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SWiFT V27 Wake Steering Loads Analysis

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Background

This document summarizes an analysis that was performed to identify the conditions for safe operation of the SWiFT V27 rotors during the FY16/17 wake steering experimental campaign. This experimental campaign requires operation of the turbines that is fundamentally different from how they were designed to operate. Simulations were performed using the wind turbine aeroelastic simulator FAST and the V27 reference model produced by the SNL wind energy department. The loads analysis performed was in accordance with the IEC 61400-1 Ed. 3 wind turbine design standard, using the power production (IEC DLC 1.*x*) and extreme case, parked (IEC DLC 6.*x*) design load cases. Conclusions about the region of allowed operation and turbine alarm settings are included.

YAW MISALIGNMENT LOADS ANALYSIS – ULTIMATE LOADS

Analysis Description

IEC Design Loads Cases Tested:

- ➢ IEC analysis currently employs DLC 1.1, 1.2, 1.3, 1.4, 1.5, 6.1, 6.2 and 6.3

Simulation Limitations:

- SWiFT Simulink controller was used but to include yaw error in this version of the controller the yaw control was turned off
  - Loads may be higher in the simulations for turbulent DLC's where wind direction is changing
- Complete controller fault detection not included
- How accurate is FAST at large yaw errors? FAST GDW model had non-realistic outputs for the DLC 1.4 case and was not used.
  - Dynamic stall model usage compared with this case, and loads did not change

Table 2 – Design load cases

Design situation	DLC	Wind condition	Other conditions	Type of analysis	Partial safety factors
1) Power production					
2) Power production plus occurrence of fault	2.1	NTM $V_{in} < V_{hub} < V_{out}$	Control system fault or loss of electrical network	U	N
	2.2	NTM $V_{in} < V_{hub} < V_{out}$	Protection system or preceding internal electrical fault	U	A
	2.3	EOG $V_{hub} = V_r \pm 2$ m/s and V_{out}	External or internal electrical fault including loss of electrical network	U	A
	2.4	NTM $V_{in} < V_{hub} < V_{out}$	Control, protection, or electrical system faults including loss of electrical network	F	*
3) Start up	3.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	3.2	EOG $V_{hub} = V_{in}$, $V_r \pm$ 2m/s and V_{out}		U	N
	3.3	EDC $V_{hub} = V_{in}$, $V_r \pm$ 2m/s and V_{out}		U	N
4) Normal shut down	4.1	NWP $V_{in} < V_{hub} < V_{out}$		F	*
	4.2	EOG $V_{hub} = V_r \pm 2$ m/s and V_{out}		U	N
5) Emergency shut down	5.1	NTM $V_{hub} = V_r \pm 2$ m/s and V_{out}		U	N
6) Parked (standing still or idling)					
	6.4	NTM $V_{hub} < 0{,}7\ V_{ref}$		F	*
7) Parked and fault conditions	7.1	EWM 1-year recurrence period		U	A
8) Transport, assembly, maintenance and repair	8.1	NTM V_{maint} to be stated by the manufacturer		U	T

Analysis Description

Definition of Loads Exceedance:

1. Where the load exceeds known blade/system strength
2. In the absence of a known strength, where the yawed case load exceeds the baseline load

Test Name	Simulation Conditions	Conclusion
Baseline Case	• Yaw misalignment: -18:2:18 deg • Wind Speed: 5:1:25 m/s • Turbulent Seeds: 12 • Yaw controller: none	Baseline loads are generated for comparison
Yawed Case 1	• Yaw misalignment: -40:5:40 deg • Wind Speed: 5:1:20 m/s • Turbulent Seeds: 12 • Yaw controller: none	Wind speed needs to be reduced to not exceed maximum blade root bending moment
Yawed Case 2	• Yaw misalignment: -40:5:40 deg • Wind Speed: 5:1:15 m/s • Turbulent Seeds: 12 • Yaw controller: none	Some loads are exceeded with this range of yaw misalignment and wind speed
Yawed Case 3	• Yaw misalignment: -40:5:40 deg • Wind Speed: 5:1:15 m/s • Turbulent Seeds: 12 • Yaw controller: Center-Seeking Wake Steering Controller	Actual experiment controller tested with slight reduction in loads, but with some exceedance

Analysis Description

Definition of some known blade/system strengths:

Loads Analysis – Blade Loads

Load Direction	Design Strength	SWiFT Rotor Design Loads	SWiFT yawed case 3
Root Edge Bending	210 kN-m	191.0 kN-m (DLC 1.3 ETM; 13 m/s, -18 deg yaw)	209.9 kN-m (DLC 1.3 ETM; 14 m/s, -40 deg yaw)
Blade Tip Deflection	1.97 m	1.01 m (DLC 1.3 ETM, 18 m/s, -18 deg yaw)	1.05 m (DLC 1.3 ETM, 15 m/s, 35 deg yaw)

Loads Analysis – Tower Loads

Load Direction	Design Strength	SWiFT Rotor Design Loads	SWiFT yawed case 3
Nacelle Yaw Moment	n/a	134.7 kN-m (DLC 1.3 ETM, 25 m/s, -18 deg yaw)	139.1 kN-m (DLC 1.3 ETM, 14 m/s, 40 deg yaw)
Tower Base Moment (side-side)	4510 kN-m	1388.4 kN-m (DLC 6.1 EWM50, 15 deg)	1388.4 kN-m (DLC 6.1 EWM50, 15 deg yaw)
Tower Base Moment (fore-aft)	4510 kN-m	1747.3 kN-m (DLC 1.3 ETM, 17 m/s, 16 deg yaw)	1638.5 kN-m (DLC 1.3 ETM, 13 m/s, 10 deg yaw)

Yawed Loads Comparison

Comparison of the **Yawed Case 3** (5:1:15 m/s, -40:5:40 deg yaw, yaw controller) to the **Baseline Case** (5:1:25 m/s, -18:2:18 deg yaw)

**shown as Design loads (with IEC recommended safety factor)

DLC Name	MaxFlapStrain	in File
Ratio: yaw/orig	1.036190293	n/a
IECDLC1p3ETM	2150.155459	out/IECDLC1p3ETM_yaw35_15mps_seed6.out
IECDLC1p3ETM	2075.058484	out/IECDLC1p3ETM_yaw-18_18mps_seed10.out
DLC Name	MinFlapStrain	in File
Ratio: yaw/orig	1.120276805	n/a
IECDLC1p4ECD	-2101.136913	out/IECDLC1p4ECD_yaw-35_ECD-R-2.0.out
IECDLC1p3ETM	-1875.551564	out/IECDLC1p3ETM_yaw16_25mps_seed9.out
DLC Name	MaxEdgeStrain	in File
Ratio: yaw/orig	1.121744119	n/a
IECDLC1p4ECD	1463.62333	out/IECDLC1p4ECD_yaw40_ECD+R-2.0.out
IECDLC1p3ETM	1304.774685	out/IECDLC1p3ETM_yaw-14_25mps_seed3.out
DLC Name	MinEdgeStrain	in File
Ratio: yaw/orig	0.970256411	n/a
IECDLC1p3ETM	-1114.941104	out/IECDLC1p3ETM_yaw35_13mps_seed11.out
IECDLC1p3ETM	-1149.120059	out/IECDLC1p3ETM_yaw8_25mps_seed2.out
DLC Name	MaxOoPDefl	in File
Ratio: yaw/orig	1.04079175	n/a
IECDLC1p3ETM	1.049840055	out/IECDLC1p3ETM_yaw35_15mps_seed6.out
IECDLC1p3ETM	1.008693675	out/IECDLC1p3ETM_yaw-18_18mps_seed10.out
DLC Name	MinOoPDefl	in File
Ratio: yaw/orig	1.407219293	n/a
IECDLC1p4ECD	-1.03928913	out/IECDLC1p4ECD_yaw-35_ECD-R-2.0.out
IECDLC1p3ETM	-0.73854099	out/IECDLC1p3ETM_yaw16_25mps_seed9.out

Strain: there is an increase, but the magnitude of the microstrain is within the limit for safe operation of composites

Out of Plane Deflection: the increase is within the limit for the turbine, with a design displacement of 1.97m allowed.

Yawed Loads Comparison

DLC Name	AmplRootFxb1Fyb1	in File
Ratio: yaw/orig	1	n/a
IECDLC6p2EWM50	29.8472959	out/IECDLC6p2EWM50_EWM50+90.out
IECDLC6p2EWM50	29.8472959	out/IECDLC6p2EWM50_EWM50+90.out
DLC Name	AmplRootFxb2Fyb2	in File
Ratio: yaw/orig	1.063468878	n/a
IECDLC1p3ETM	29.98894024	out/IECDLC1p3ETM_yaw-40_14mps_seed4.out
IECDLC1p3ETM	28.19917053	out/IECDLC1p3ETM_yaw-12_25mps_seed3.out
DLC Name	AmplRootFxb3Fyb3	in File
Ratio: yaw/orig	0.955684462	n/a
IECDLC1p3ETM	27.76546099	out/IECDLC1p3ETM_yaw-40_15mps_seed11.out
IECDLC1p3ETM	29.05295846	out/IECDLC1p3ETM_yaw-18_25mps_seed4.out
DLC Name	AmplRootMxb1Myb1	in File
Ratio: yaw/orig	1.052906286	n/a
IECDLC1p3ETM	201.1327114	out/IECDLC1p3ETM_yaw-35_14mps_seed1.out
IECDLC1p3ETM	191.0262235	out/IECDLC1p3ETM_yaw-18_13mps_seed11.out
DLC Name	AmplRootMxb2Myb2	in File
Ratio: yaw/orig	1.101207272	n/a
IECDLC1p3ETM	209.8890249	out/IECDLC1p3ETM_yaw-40_14mps_seed4.out
IECDLC1p3ETM	190.5990182	out/IECDLC1p3ETM_yaw-18_13mps_seed11.out
DLC Name	AmplRootMxb3Myb3	in File
Ratio: yaw/orig	1.071942835	n/a
IECDLC1p3ETM	198.6749892	out/IECDLC1p3ETM_yaw-40_15mps_seed11.out
IECDLC1p3ETM	185.3410301	out/IECDLC1p3ETM_yaw-14_14mps_seed7.out

Blade Root Shear Force: there is an increase for Blade 2, but the Blade 1 force for the baseline case is nearly as high as the increased yawed case 3 loads

Blade Root Moment: there is an increase, but it is within the design strength of 210 kN-m

Yawed Loads Comparison

DLC Name	MaxYawBrFxn	in File
Ratio: yaw/orig	0.977556296	n/a
IECDLC1p3ETM	51.203475	out/IECDLC1p3ETM_yaw-40_15mps_seed6.out
IECDLC1p3ETM	52.379055	out/IECDLC1p3ETM_yaw16_14mps_seed8.out
DLC Name	MinYawBrFxn	in File
Ratio: yaw/orig	1.245584721	n/a
IECDLC1p4ECD	-38.84625	out/IECDLC1p4ECD_yaw-40_ECD-R-2.0.out
IECDLC1p3ETM	-31.18716	out/IECDLC1p3ETM_yaw-18_6mps_seed2.out
DLC Name	MaxYawBrFyn	in File
Ratio: yaw/orig	1	n/a
IECDLC6p2EWM50	36.91611	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p2EWM50	36.91611	out/IECDLC6p2EWM50_EWM50-80.out
DLC Name	MinYawBrFyn	in File
Ratio: yaw/orig	1	n/a
IECDLC6p1EWM50	-44.28891	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p1EWM50	-44.28891	out/IECDLC6p1EWM50_EWM50+15.out
DLC Name	MaxYawBrMxn	in File
Ratio: yaw/orig	1	n/a
IECDLC6p2EWM50	170.5539	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p2EWM50	170.5539	out/IECDLC6p2EWM50_EWM50+95.out
DLC Name	MinYawBrMxn	in File
Ratio: yaw/orig	1	n/a
IECDLC6p2EWM50	-162.5756	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p2EWM50	-162.5756	out/IECDLC6p2EWM50_EWM50-80.out
DLC Name	MaxYawBrMyn	in File
Ratio: yaw/orig	0.828966181	n/a
IECDLC1p3ETM	165.1563	out/IECDLC1p3ETM_yaw-40_15mps_seed9.out
IECDLC1p3ETM	199.23165	out/IECDLC1p3ETM_yaw18_25mps_seed10.out
DLC Name	MinYawBrMyn	in File
Ratio: yaw/orig	1.560793979	n/a
IECDLC1p4ECD	-239.3739	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p3ETM	-153.36675	out/IECDLC1p3ETM_yaw-18_25mps_seed5.out
DLC Name	AmplYawBrMxnMyn	in File
Ratio: yaw/orig	1.092557968	n/a
IECDLC1p4ECD	240.9494779	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p3ETM	220.5370194	out/IECDLC1p3ETM_yaw18_25mps_seed3.out
DLC Name	MaxYawBrMzn	in File
Ratio: yaw/orig	1.112414757	n/a
IECDLC1p3ETM	125.193465	out/IECDLC1p3ETM_yaw-35_13mps_seed1.out
IECDLC1p3ETM	112.542075	out/IECDLC1p3ETM_yaw0_25mps_seed11.out
DLC Name	MinYawBrMzn	in File
Ratio: yaw/orig	1.033010417	n/a
IECDLC1p3ETM	-139.104	out/IECDLC1p3ETM_yaw40_14mps_seed10.out
IECDLC1p3ETM	-134.658855	out/IECDLC1p3ETM_yaw-18_25mps_seed3.out

Yaw Bearing Plane Forces: minimum Fx,n amplitude increases, but the magnitude is less than the maximum Fx,n force so it is within the original design strength

Yaw Bearing – Fore-Aft Moment: there is a 20% increase (-239/+199) in the magnitude of the maximum moment, resulting from the additional yaw misalignment. It is not clear if this is an issue, or for which component. There are directional differences for the nacelle yaw feet.

Yaw Bearing – Overturn Moment Amplitude: there is a 9% increase in the amplitude of the maximum overturning moment caused by the DLC 1.4 extreme gust with direction change (see slides on 'Nacelle Overturning Moment')

Yaw Bearing – Yaw Moment: there is a 3% increase in the magnitude of the maximum moment, resulting from the additional yaw misalignment.

Yawed Loads Comparison

DLC Name	MaxRotThrust	in File
Ratio: yaw/orig	0.993402099	n/a
IECDLC1p3ETM	53.25426	out/IECDLC1p3ETM_yaw-40_15mps_seed11.out
IECDLC1p3ETM	53.60796	out/IECDLC1p3ETM_yaw10_16mps_seed11.out
DLC Name	MinRotThrust	in File
Ratio: yaw/orig	1.666832801	n/a
IECDLC1p4ECD	-35.667405	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p4ECD	-21.39831	out/IECDLC1p4ECD_yaw-18_ECD-R-2.0.out
DLC Name	MaxLSShftMxa	in File
Ratio: yaw/orig	1	n/a
IECDLC6p2EWM50	121.7491	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p2EWM50	121.7491	out/IECDLC6p2EWM50_EWM50+95.out
DLC Name	MinLSShftMxa	in File
Ratio: yaw/orig	1	n/a
IECDLC6p1EWM50	-138.00915	out/IECDLC6p1EWM50_EWM50+00.out
IECDLC6p1EWM50	-138.00915	out/IECDLC6p1EWM50_EWM50+00.out
DLC Name	MaxLSSTipMys	in File
Ratio: yaw/orig	0.837876469	n/a
IECDLC1p4ECD	156.6891	out/IECDLC1p4ECD_yaw40_ECD+R.out
IECDLC1p3ETM	187.0074	out/IECDLC1p3ETM_yaw18_25mps_seed6.out
DLC Name	MinLSSTipMys	in File
Ratio: yaw/orig	1.070796087	n/a
IECDLC1p4ECD	-171.5796	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p3ETM	-160.23555	out/IECDLC1p3ETM_yaw-18_25mps_seed4.out
DLC Name	MaxLSSTipMzs	in File
Ratio: yaw/orig	1.093543136	n/a
IECDLC1p3ETM	127.230075	out/IECDLC1p3ETM_yaw-35_13mps_seed1.out
IECDLC1p3ETM	116.346645	out/IECDLC1p3ETM_yaw-12_12mps_seed11.out
DLC Name	MinLSSTipMzs	in File
Ratio: yaw/orig	1.056715733	n/a
IECDLC1p3ETM	-135.54405	out/IECDLC1p3ETM_yaw40_14mps_seed10.out
IECDLC1p3ETM	-128.26917	out/IECDLC1p3ETM_yaw-14_25mps_seed12.out

Minimum Rotor Thrust: there is an increase in the magnitude, but the value is lower than the “positive” rotor thrust. Are there any differences in how the mechanical components can handle a positive or negative thrust force? (see slides on ‘Nacelle Overturning Moment’)

Minimum Low Speed Shaft Tip Moment (top-bottom): An increase in magnitude of the minimum moment, but less than the baseline maximum moment.

Minimum Low Speed Shaft Tip Moment (side-side): An increase in magnitude of 6% due to yaw error. The magnitude is less than the maximum LSS bending moment of 187 kN-m from the baseline case (My,s).

Yawed Loads Comparison

DLC Name	MaxTwrBsMxt	in File
Ratio: yaw/orig	1	n/a
IECDLC6p1EWM50	1388.3805	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p1EWM50	1388.3805	out/IECDLC6p1EWM50_EWM50+15.out
DLC Name	MinTwrBsMxt	in File
Ratio: yaw/orig	1	n/a
IECDLC6p2EWM50	-1302.664	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p2EWM50	-1302.664	out/IECDLC6p2EWM50_EWM50-80.out
DLC Name	MaxTwrBsMyt	in File
Ratio: yaw/orig	0.937734683	n/a
IECDLC1p3ETM	1638.5085	out/IECDLC1p3ETM_yaw10_13mps_seed7.out
IECDLC1p3ETM	1747.305	out/IECDLC1p3ETM_yaw16_17mps_seed11.out
DLC Name	MinTwrBsMyt	in File
Ratio: yaw/orig	1.121333768	n/a
IECDLC1p4ECD	-1216.5174	out/IECDLC1p4ECD_yaw-30_ECD-R-2.0.out
IECDLC1p3ETM	-1084.8843	out/IECDLC1p3ETM_yaw0_5mps_seed2.out

Tower Base Moment: The maximum tower base moment is seen by the baseline case at 16-deg yaw misalignment. This design load is much smaller than the design strength for the tower platform of 4510 kN-m.

Root Bending Moment

Yawed Case 1: -40:5:40 deg yaw, 5:1:20 m/s, 12 turbulent seeds, Class III-C

DLC Name	AmplRootMxb1Myb1	with Safety Factor	in File
IECDLC1p2NTM	153.46	207.17	out/IECDLC1p2NTM_yaw-40_20mps_seed12.out
IECDLC1p3ETM	156.99	**211.94**	out/IECDLC1p3ETM_**yaw-40_19mps**_seed12.out
IECDLC1p4ECD	146.19	197.36	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	114.00	153.90	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	138.15	186.51	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	160.47	176.51	out/IECDLC6p2EWM50_EWM50+90.out
IECDLC6p3EWM01	90.37	122.00	out/IECDLC6p3EWM01_EWM01+20.out
DLC Name	AmplRootMxb2Myb2	with Safety Factor	in File
IECDLC1p2NTM	149.97	202.46	out/IECDLC1p2NTM_yaw-35_20mps_seed12.out
IECDLC1p3ETM	165.49	**223.41**	out/IECDLC1p3ETM_**yaw-40_19mps**_seed12.out
IECDLC1p4ECD	146.24	197.43	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	113.71	153.52	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	70.29	94.89	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.54	68.79	out/IECDLC6p2EWM50_EWM50-90.out
IECDLC6p3EWM01	82.87	111.88	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	AmplRootMxb3Myb3	with Safety Factor	in File
IECDLC1p2NTM	148.01	199.82	out/IECDLC1p2NTM_yaw-35_19mps_seed12.out
IECDLC1p3ETM	157.59	**212.75**	out/IECDLC1p3ETM_**yaw-40_18mps**_seed7.out
IECDLC1p4ECD	146.23	197.40	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	113.95	153.84	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	93.20	125.82	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.32	68.55	out/IECDLC6p2EWM50_EWM50+85.out
IECDLC6p3EWM01	76.16	102.82	out/IECDLC6p3EWM01_EWM01+25.out

Baseline Case: -18:2:18 deg yaw, 5:1:25 m/s, 12 turbulent seeds, Class III-C

DLC Name	AmplRootMxb1Myb1	with Safety Factor	in File
IECDLC1p2NTM	120.98	163.32	out/IECDLC1p2NTM_yaw-18_13mps_seed11.out
IECDLC1p3ETM	141.50	191.03	out/IECDLC1p3ETM_yaw-18_13mps_seed11.out
IECDLC1p4ECD	127.20	171.73	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	100.21	135.28	out/IECDLC1p5EWS_yaw-18_EWSV+11.0.out
IECDLC6p1EWM50	138.15	186.51	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	160.47	176.51	out/IECDLC6p2EWM50_EWM50+90.out
IECDLC6p3EWM01	90.37	122.00	out/IECDLC6p3EWM01_EWM01+20.out
DLC Name	AmplRootMxb2Myb2	with Safety Factor	in File
IECDLC1p2NTM	127.94	172.72	out/IECDLC1p2NTM_yaw-10_17mps_seed11.out
IECDLC1p3ETM	141.18	190.60	out/IECDLC1p3ETM_yaw-18_13mps_seed11.out
IECDLC1p4ECD	127.24	171.78	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	99.44	134.24	out/IECDLC1p5EWS_yaw-18_EWSV+11.0.out
IECDLC6p1EWM50	70.29	94.89	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.54	68.79	out/IECDLC6p2EWM50_EWM50-90.out
IECDLC6p3EWM01	82.87	111.88	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	AmplRootMxb3Myb3	with Safety Factor	in File
IECDLC1p2NTM	123.86	167.21	out/IECDLC1p2NTM_yaw-18_17mps_seed11.out
IECDLC1p3ETM	137.29	185.34	out/IECDLC1p3ETM_yaw-14_14mps_seed7.out
IECDLC1p4ECD	127.16	171.66	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	100.11	135.14	out/IECDLC1p5EWS_yaw-16_EWSV+11.0.out
IECDLC6p1EWM50	93.20	125.82	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.32	68.55	out/IECDLC6p2EWM50_EWM50+85.out
IECDLC6p3EWM01	76.16	102.82	out/IECDLC6p3EWM01_EWM01+25.out

Maximum amplitude of the blade root moment for wind speeds up to 20 m/s (yawed case and baseline case) is from the DLC 1.3 extreme turbulence model.

- Yawed Case 1 blade root bending exceeds design strength of 210 kNm

Root Bending Moment

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Yawed Case 2: -40:5:40 deg yaw, 5:1:15 m/s, 12 turbulent seeds, Class III-C

DLC Name	AmplRootMxb1Myb1	with Safety Factor	in File
IECDLC1p2NTM	138.50	186.98	out/IECDLC1p2NTM_yaw-40_15mps_seed1.out
IECDLC1p3ETM	148.99	**201.13**	out/IECDLC1p3ETM_**yaw-35_14mps**_seed1.out
IECDLC1p4ECD	146.19	197.36	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	114.00	153.90	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	138.15	186.51	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	160.47	176.51	out/IECDLC6p2EWM50_EWM50+90.out
IECDLC6p3EWM01	90.37	122.00	out/IECDLC6p3EWM01_EWM01+20.out
DLC Name	AmplRootMxb2Myb2	with Safety Factor	in File
IECDLC1p2NTM	138.80	187.38	out/IECDLC1p2NTM_yaw-40_15mps_seed1.out
IECDLC1p3ETM	155.46	**209.87**	out/IECDLC1p3ETM_**yaw-40_14mps**_seed4.out
IECDLC1p4ECD	146.24	197.43	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	113.71	153.52	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	70.29	94.89	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.54	68.79	out/IECDLC6p2EWM50_EWM50-90.out
IECDLC6p3EWM01	82.87	111.88	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	AmplRootMxb3Myb3	with Safety Factor	in File
IECDLC1p2NTM	137.00	184.95	out/IECDLC1p2NTM_yaw-40_14mps_seed4.out
IECDLC1p3ETM	147.17	**198.67**	out/IECDLC1p3ETM_**yaw-40_15mps**_seed11.out
IECDLC1p4ECD	146.23	197.40	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	113.95	153.84	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	93.20	125.82	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.32	68.55	out/IECDLC6p2EWM50_EWM50+85.out
IECDLC6p3EWM01	76.16	102.82	out/IECDLC6p3EWM01_EWM01+25.out

Baseline Case: -18:2:18 deg yaw, 5:1:25 m/s, 12 turbulent seeds, Class III-C

DLC Name	AmplRootMxb1Myb1	with Safety Factor	in File
IECDLC1p2NTM	120.98	163.32	out/IECDLC1p2NTM_yaw-18_13mps_seed11.out
IECDLC1p3ETM	141.50	191.03	out/IECDLC1p3ETM_yaw-18_13mps_seed11.out
IECDLC1p4ECD	127.20	171.73	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	100.21	135.28	out/IECDLC1p5EWS_yaw-18_EWSV+11.0.out
IECDLC6p1EWM50	138.15	186.51	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	160.47	176.51	out/IECDLC6p2EWM50_EWM50+90.out
IECDLC6p3EWM01	90.37	122.00	out/IECDLC6p3EWM01_EWM01+20.out
DLC Name	AmplRootMxb2Myb2	with Safety Factor	in File
IECDLC1p2NTM	127.94	172.72	out/IECDLC1p2NTM_yaw-10_17mps_seed11.out
IECDLC1p3ETM	141.18	190.60	out/IECDLC1p3ETM_yaw-18_13mps_seed11.out
IECDLC1p4ECD	127.24	171.78	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	99.44	134.24	out/IECDLC1p5EWS_yaw-18_EWSV+11.0.out
IECDLC6p1EWM50	70.29	94.89	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.54	68.79	out/IECDLC6p2EWM50_EWM50-90.out
IECDLC6p3EWM01	82.87	111.88	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	AmplRootMxb3Myb3	with Safety Factor	in File
IECDLC1p2NTM	123.86	167.21	out/IECDLC1p2NTM_yaw-18_17mps_seed11.out
IECDLC1p3ETM	137.29	185.34	out/IECDLC1p3ETM_yaw-14_14mps_seed7.out
IECDLC1p4ECD	127.16	171.66	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	100.11	135.14	out/IECDLC1p5EWS_yaw-16_EWSV+11.0.out
IECDLC6p1EWM50	93.20	125.82	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.32	68.55	out/IECDLC6p2EWM50_EWM50+85.out
IECDLC6p3EWM01	76.16	102.82	out/IECDLC6p3EWM01_EWM01+25.out

Limiting the wind speed operation to 15 m/s keeps the blade root moment within the 210 kNm strength limit.

Root Bending Moment

Yawed Case 3: -40:5:40 deg yaw, 5:1:15 m/s, yaw controller, 12 turbulent seeds, Class III-C

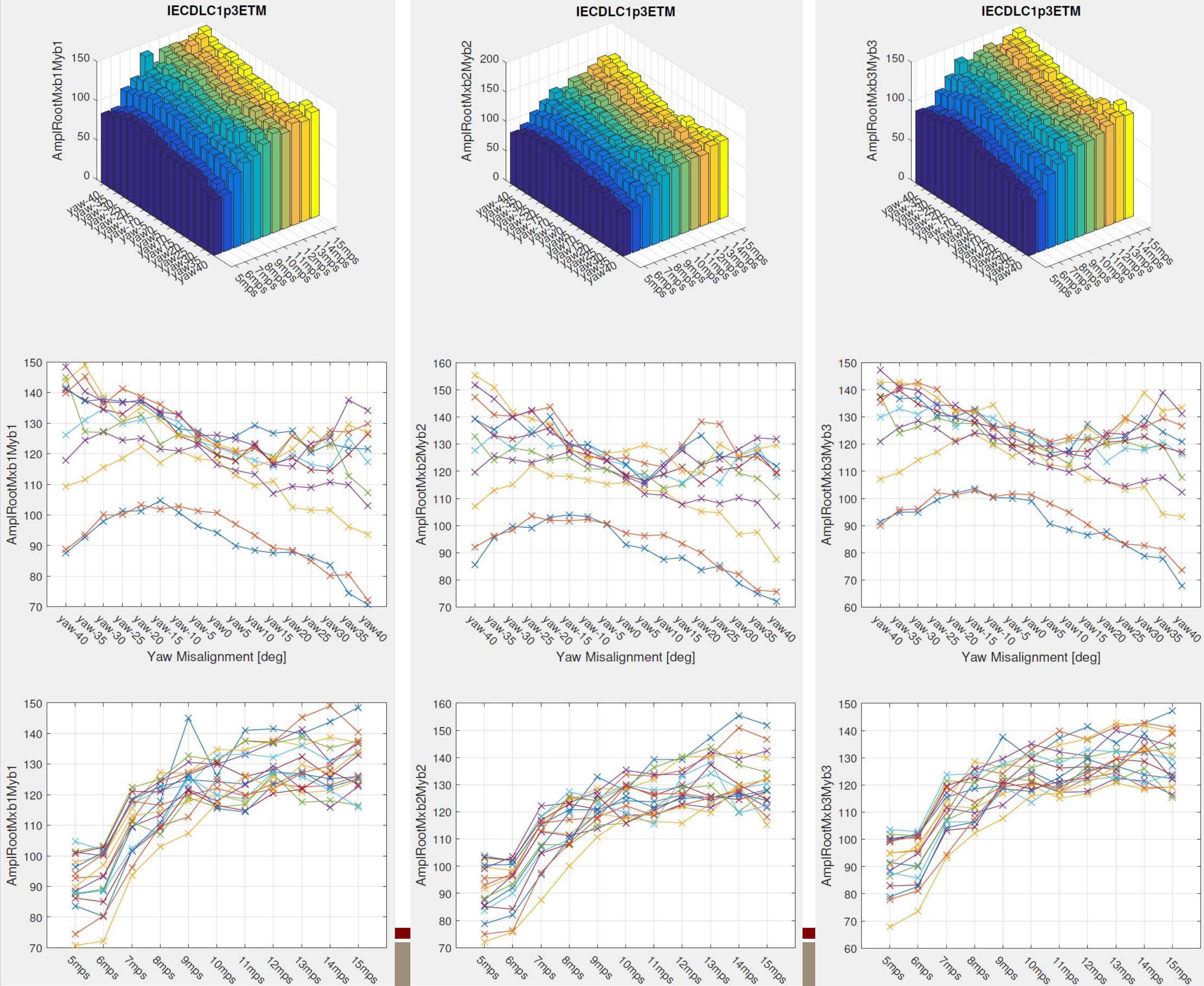
DLC Name	AmplRootMxb1Myb1	with Safety Factor	in File
IECDLC1p2NTM	138.50	186.98	out/IECDLC1p2NTM_yaw-40_15mps_seed1.out
IECDLC1p3ETM	148.99	201.13	out/IECDLC1p3ETM_yaw-35_14mps_seed1.out
IECDLC1p4ECD	146.19	197.36	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	112.53	151.92	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	138.15	186.51	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	160.47	176.51	out/IECDLC6p2EWM50_EWM50+90.out
IECDLC6p3EWM01	90.37	122.00	out/IECDLC6p3EWM01_EWM01+20.out
DLC Name	AmplRootMxb2Myb2	with Safety Factor	in File
IECDLC1p2NTM	138.80	187.38	out/IECDLC1p2NTM_yaw-40_15mps_seed1.out
IECDLC1p3ETM	155.47	209.89	out/IECDLC1p3ETM_yaw-40_14mps_seed4.out
IECDLC1p4ECD	146.24	197.43	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	112.19	151.46	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	70.29	94.89	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.54	68.79	out/IECDLC6p2EWM50_EWM50-90.out
IECDLC6p3EWM01	82.87	111.88	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	AmplRootMxb3Myb3	with Safety Factor	in File
IECDLC1p2NTM	137.00	184.95	out/IECDLC1p2NTM_yaw-40_14mps_seed4.out
IECDLC1p3ETM	147.17	198.67	out/IECDLC1p3ETM_yaw-40_15mps_seed11.out
IECDLC1p4ECD	146.23	197.40	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	112.65	152.08	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	93.20	125.82	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.32	68.55	out/IECDLC6p2EWM50_EWM50+85.out
IECDLC6p3EWM01	76.16	102.82	out/IECDLC6p3EWM01_EWM01+25.out

To not exceed the estimated design strength, maximum root moment is:
210/1.35 = 155.6 kNm (all DLC, not 6.2)
210/1.1 = 190.9 (DLC 6.2)

Baseline Case: -18:2:18 deg yaw, 5:1:25 m/s, 12 turbulent seeds, Class III-C

DLC Name	AmplRootMxb1Myb1	with Safety Factor	in File
IECDLC1p2NTM	120.98	163.32	out/IECDLC1p2NTM_yaw-18_13mps_seed11.out
IECDLC1p3ETM	141.50	191.03	out/IECDLC1p3ETM_yaw-18_13mps_seed11.out
IECDLC1p4ECD	127.20	171.73	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	100.21	135.28	out/IECDLC1p5EWS_yaw-18_EWSV+11.0.out
IECDLC6p1EWM50	138.15	186.51	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	160.47	176.51	out/IECDLC6p2EWM50_EWM50+90.out
IECDLC6p3EWM01	90.37	122.00	out/IECDLC6p3EWM01_EWM01+20.out
DLC Name	AmplRootMxb2Myb2	with Safety Factor	in File
IECDLC1p2NTM	127.94	172.72	out/IECDLC1p2NTM_yaw-10_17mps_seed11.out
IECDLC1p3ETM	141.18	190.60	out/IECDLC1p3ETM_yaw-18_13mps_seed11.out
IECDLC1p4ECD	127.24	171.78	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	99.44	134.24	out/IECDLC1p5EWS_yaw-18_EWSV+11.0.out
IECDLC6p1EWM50	70.29	94.89	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.54	68.79	out/IECDLC6p2EWM50_EWM50-90.out
IECDLC6p3EWM01	82.87	111.88	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	AmplRootMxb3Myb3	with Safety Factor	in File
IECDLC1p2NTM	123.86	167.21	out/IECDLC1p2NTM_yaw-18_17mps_seed11.out
IECDLC1p3ETM	137.29	185.34	out/IECDLC1p3ETM_yaw-14_14mps_seed7.out
IECDLC1p4ECD	127.16	171.66	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	100.11	135.14	out/IECDLC1p5EWS_yaw-16_EWSV+11.0.out
IECDLC6p1EWM50	93.20	125.82	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	62.32	68.55	out/IECDLC6p2EWM50_EWM50+85.out
IECDLC6p3EWM01	76.16	102.82	out/IECDLC6p3EWM01_EWM01+25.out

To not exceed the Baseline loads, maximum root moment is:
191/1.35 = 141.5 kNm (all DLC, not 6.2)
191/1.1 = 173.7 kNm (DLC 6.2)



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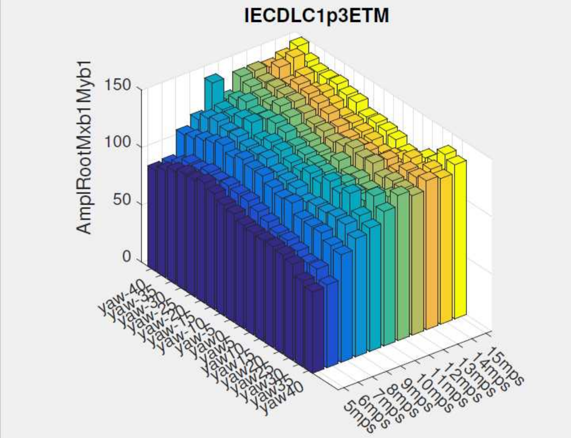
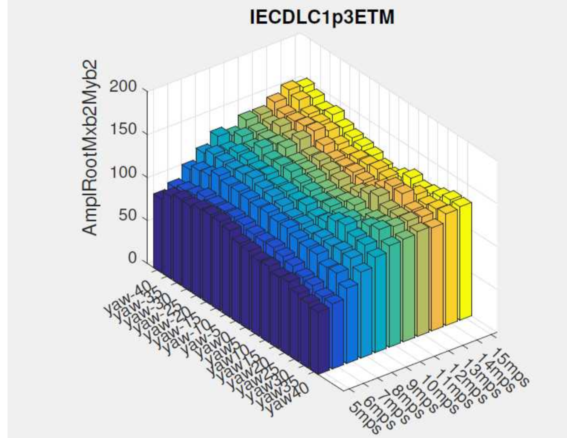
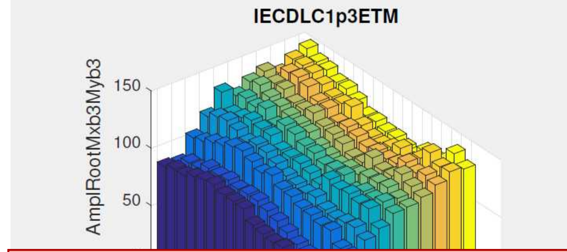
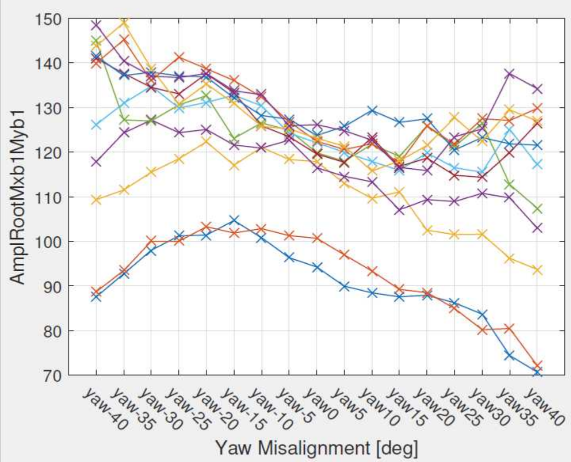


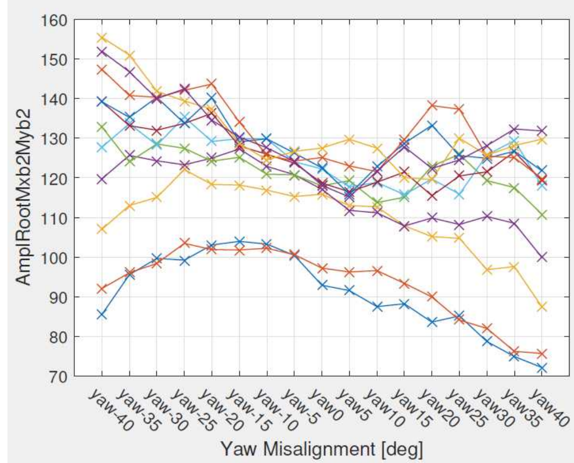


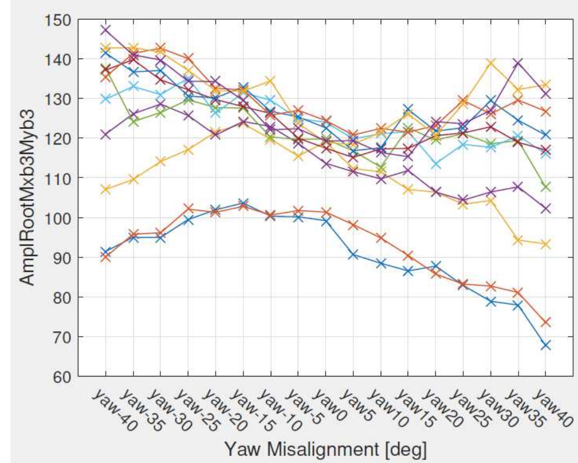


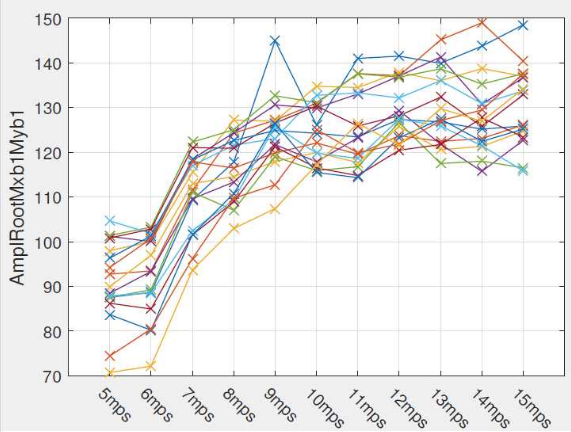
Maximum Root Moment, Characteristic Loads (kNm):

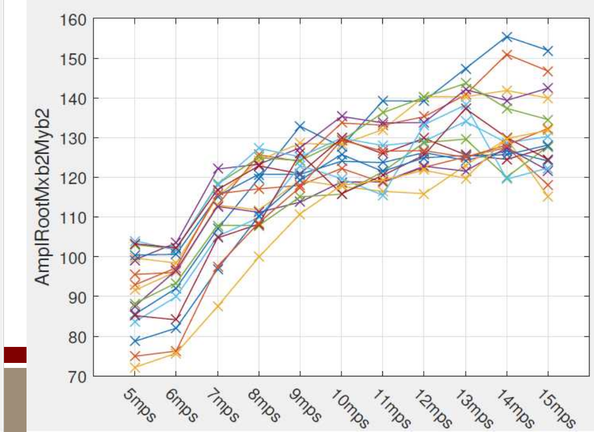
- Baseline Case: 141.5
- Est. Strength: 155.6

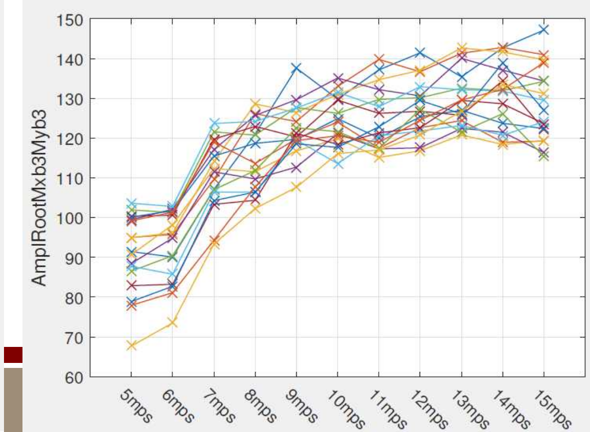












Nacelle Yaw Moment

Yawed Case 1: -40:5:40 deg yaw, 5:1:20 m/s, 12 turbulent seeds, Class III-C

DLC Name	MaxYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	73.27	98.92	out/IECDLC1p2NTM_yaw-40_14mps_seed1.out
IECDLC1p3ETM	92.74	**125.19**	out/IECDLC1p3ETM_**yaw-35_13mps**_seed1.out
IECDLC1p4ECD	55.99	75.59	out/IECDLC1p4ECD_yaw0_ECD-R.out
IECDLC1p5EWS	30.52	41.20	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	53.23	71.86	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	46.98	51.67	out/IECDLC6p2EWM50_EWM50+80.out
IECDLC6p3EWM01	40.71	54.95	out/IECDLC6p3EWM01_EWM01+25.out
DLC Name	MinYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	-79.15	-106.86	out/IECDLC1p2NTM_yaw40_15mps_seed4.out
IECDLC1p3ETM	-103.04	**-139.10**	out/IECDLC1p3ETM_**yaw40_14mps**_seed10.out
IECDLC1p4ECD	-60.82	-82.11	out/IECDLC1p4ECD_yaw0_ECD+R.out
IECDLC1p5EWS	-31.72	-42.82	out/IECDLC1p5EWS_yaw40_EWSV+14.0.out
IECDLC6p1EWM50	-21.58	-29.13	out/IECDLC6p1EWM50_EWM50-15.out
IECDLC6p2EWM50	-47.05	-51.76	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	-32.10	-43.33	out/IECDLC6p3EWM01_EWM01-30.out

Yaw moment magnitude increases by 3%. The maxima occur at lower wind speeds and extreme turbulence.

Baseline Case: -18:2:18 deg yaw, 5:1:20 m/s, 12 turbulent seeds, Class III-C

DLC Name	MaxYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	70.16	94.72	out/IECDLC1p2NTM_yaw16_25mps_seed11.out
IECDLC1p3ETM	83.36	112.54	out/IECDLC1p3ETM_yaw0_25mps_seed11.out
IECDLC1p4ECD	58.91	79.53	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	16.02	21.63	out/IECDLC1p5EWS_yaw-18_EWSV+10.0.out
IECDLC6p1EWM50	53.23	71.86	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	46.98	51.67	out/IECDLC6p2EWM50_EWM50+80.out
IECDLC6p3EWM01	40.71	54.95	out/IECDLC6p3EWM01_EWM01+25.out
DLC Name	MinYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	-87.82	-118.56	out/IECDLC1p2NTM_yaw-16_25mps_seed8.out
IECDLC1p3ETM	-99.75	-134.66	out/IECDLC1p3ETM_yaw-18_25mps_seed3.out
IECDLC1p4ECD	-64.06	-86.48	out/IECDLC1p4ECD_yaw12_ECD+R+2.0.out
IECDLC1p5EWS	-24.81	-33.50	out/IECDLC1p5EWS_yaw-18_EWSV-20.0.out
IECDLC6p1EWM50	-21.58	-29.13	out/IECDLC6p1EWM50_EWM50-15.out
IECDLC6p2EWM50	-47.05	-51.76	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	-32.10	-43.33	out/IECDLC6p3EWM01_EWM01-30.out

DLC 1.3 simulations have the highest magnitudes, with 1.2 and 1.4 at significantly lower maximum values.

Nacelle Yaw Moment

Yawed Case 2: -40:5:40 deg yaw, 5:1:15 m/s, 12 turbulent seeds, Class III-C

DLC Name	MaxYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	73.27	98.92	out/IECDLC1p2NTM_yaw-40_14mps_seed1.out
IECDLC1p3ETM	92.74	**125.19**	out/IECDLC1p3ETM_**yaw-35_13mps**_seed1.out
IECDLC1p4ECD	55.99	75.59	out/IECDLC1p4ECD_yaw0_ECD-R.out
IECDLC1p5EWS	30.52	41.20	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	53.23	71.86	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	46.98	51.67	out/IECDLC6p2EWM50_EWM50+80.out
IECDLC6p3EWM01	40.71	54.95	out/IECDLC6p3EWM01_EWM01+25.out
DLC Name	MinYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	-79.15	-106.86	out/IECDLC1p2NTM_yaw40_15mps_seed4.out
IECDLC1p3ETM	-103.04	**-139.10**	out/IECDLC1p3ETM_**yaw40_14mps**_seed10.out
IECDLC1p4ECD	-60.82	-82.11	out/IECDLC1p4ECD_yaw0_ECD+R.out
IECDLC1p5EWS	-31.72	-42.82	out/IECDLC1p5EWS_yaw40_EWSV+14.0.out
IECDLC6p1EWM50	-21.58	-29.13	out/IECDLC6p1EWM50_EWM50-15.out
IECDLC6p2EWM50	-47.05	-51.76	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	-32.10	-43.33	out/IECDLC6p3EWM01_EWM01-30.out

Baseline Case: -18:2:18 deg yaw, 5:1:20 m/s, 12 turbulent seeds, Class III-C

DLC Name	MaxYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	70.16	94.72	out/IECDLC1p2NTM_yaw16_25mps_seed11.out
IECDLC1p3ETM	83.36	112.54	out/IECDLC1p3ETM_yaw0_25mps_seed11.out
IECDLC1p4ECD	58.91	79.53	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	16.02	21.63	out/IECDLC1p5EWS_yaw-18_EWSV+10.0.out
IECDLC6p1EWM50	53.23	71.86	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	46.98	51.67	out/IECDLC6p2EWM50_EWM50+80.out
IECDLC6p3EWM01	40.71	54.95	out/IECDLC6p3EWM01_EWM01+25.out
DLC Name	MinYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	-87.82	-118.56	out/IECDLC1p2NTM_yaw-16_25mps_seed8.out
IECDLC1p3ETM	-99.75	-134.66	out/IECDLC1p3ETM_yaw-18_25mps_seed3.out
IECDLC1p4ECD	-64.06	-86.48	out/IECDLC1p4ECD_yaw12_ECD+R+2.0.out
IECDLC1p5EWS	-24.81	-33.50	out/IECDLC1p5EWS_yaw-18_EWSV-20.0.out
IECDLC6p1EWM50	-21.58	-29.13	out/IECDLC6p1EWM50_EWM50-15.out
IECDLC6p2EWM50	-47.05	-51.76	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	-32.10	-43.33	out/IECDLC6p3EWM01_EWM01-30.out

Same as previously for Yawed Case 1.

Nacelle Yaw Moment

Yawed Case 3: -40:5:40 deg yaw, 5:1:15 m/s, yaw controller, 12 turbulent seeds, Class III-C

DLC Name	MaxYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	73.27	98.92	out/IECDLC1p2NTM_yaw-40_14mps_seed1.out
IECDLC1p3ETM	92.74	125.19	out/IECDLC1p3ETM_yaw-35_13mps_seed1.out
IECDLC1p4ECD	55.99	75.59	out/IECDLC1p4ECD_yaw0_ECD-R.out
IECDLC1p5EWS	29.94	40.42	out/IECDLC1p5EWS_yaw-40_EWSV+14.0.out
IECDLC6p1EWM50	53.23	71.86	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	46.98	51.67	out/IECDLC6p2EWM50_EWM50+80.out
IECDLC6p3EWM01	40.71	54.95	out/IECDLC6p3EWM01_EWM01+25.out
DLC Name	MinYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	-79.15	-106.86	out/IECDLC1p2NTM_yaw40_15mps_seed4.out
IECDLC1p3ETM	-103.04	-139.10	out/IECDLC1p3ETM_yaw40_14mps_seed10.out
IECDLC1p4ECD	-60.82	-82.11	out/IECDLC1p4ECD_yaw0_ECD+R.out
IECDLC1p5EWS	-31.15	-42.05	out/IECDLC1p5EWS_yaw40_EWSV+14.0.out
IECDLC6p1EWM50	-21.58	-29.13	out/IECDLC6p1EWM50_EWM50-15.out
IECDLC6p2EWM50	-47.05	-51.76	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	-32.10	-43.33	out/IECDLC6p3EWM01_EWM01-30.out

Same as previously for both yaw cases.

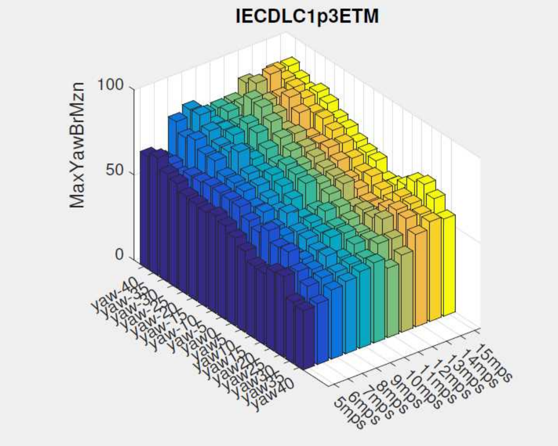
Baseline Case: -18:2:18 deg yaw, 5:1:20 m/s, 12 turbulent seeds, Class III-C

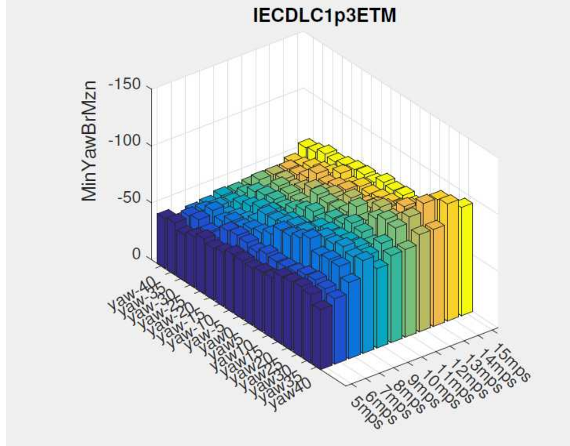
DLC Name	MaxYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	70.16	94.72	out/IECDLC1p2NTM_yaw16_25mps_seed11.out
IECDLC1p3ETM	83.36	112.54	out/IECDLC1p3ETM_yaw0_25mps_seed11.out
IECDLC1p4ECD	58.91	79.53	out/IECDLC1p4ECD_yaw-12_ECD-R+2.0.out
IECDLC1p5EWS	16.02	21.63	out/IECDLC1p5EWS_yaw-18_EWSV+10.0.out
IECDLC6p1EWM50	53.23	71.86	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	46.98	51.67	out/IECDLC6p2EWM50_EWM50+80.out
IECDLC6p3EWM01	40.71	54.95	out/IECDLC6p3EWM01_EWM01+25.out
DLC Name	MinYawBrMzn	with Safety Factor	in File
IECDLC1p2NTM	-87.82	-118.56	out/IECDLC1p2NTM_yaw-16_25mps_seed8.out
IECDLC1p3ETM	-99.75	-134.66	out/IECDLC1p3ETM_yaw-18_25mps_seed3.out
IECDLC1p4ECD	-64.06	-86.48	out/IECDLC1p4ECD_yaw12_ECD+R+2.0.out
IECDLC1p5EWS	-24.81	-33.50	out/IECDLC1p5EWS_yaw-18_EWSV-20.0.out
IECDLC6p1EWM50	-21.58	-29.13	out/IECDLC6p1EWM50_EWM50-15.out
IECDLC6p2EWM50	-47.05	-51.76	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	-32.10	-43.33	out/IECDLC6p3EWM01_EWM01-30.out

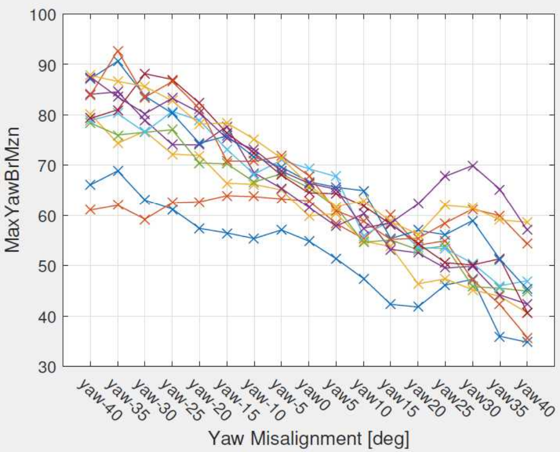
To not exceed the Baseline loads, maximum yaw moment is:

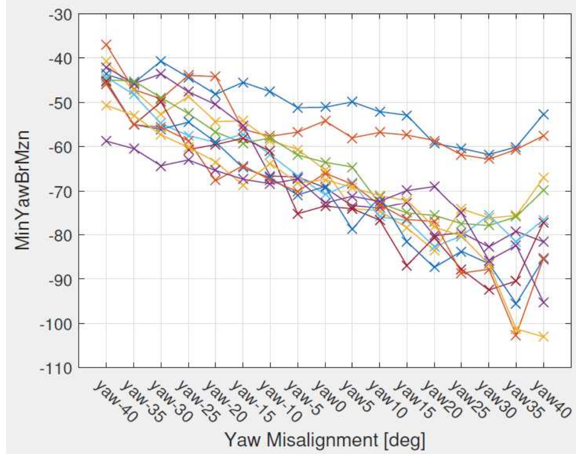
|-134.7|/1.35 = 99.8 kNm (all DLC, not 6.2)

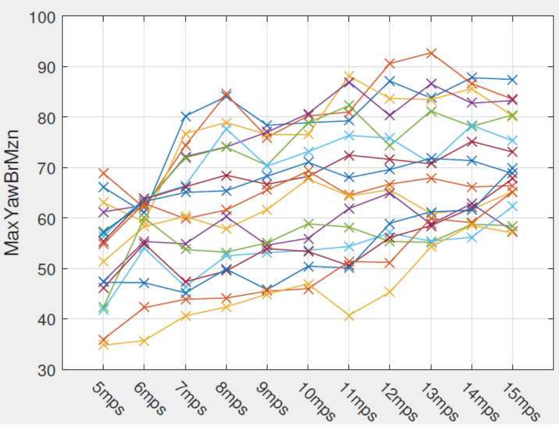
|-134.7|/1.1 = 122.4 kNm (DLC 6.2)

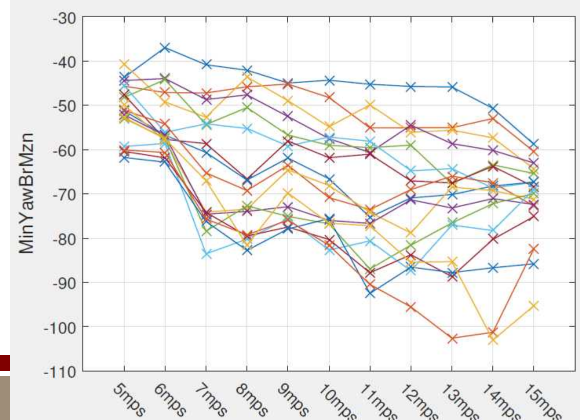












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Maximum Yaw Moment Magnitude, Characteristic Loads:

- Baseline: 99.8 kNm
- Est. Strength: unknown

To not exceed the baseline, either:

(1) Yaw errors cannot exceed -30 deg or +25 deg -- or –

(2) Wind speed cannot exceed a 10 m/s average

Nacelle Overturning Moment

Yawed Case 3: -40:5:40 deg yaw, 5:1:15 m/s, yaw controller, 12 turbulent seeds, Class III-C

DLC Name	MaxYawBrMxn	with Safety Factor	in File
IECDLC1p2NTM	54.12	73.06	out/IECDLC1p2NTM_yaw-35_15mps_seed11.out
IECDLC1p3ETM	59.94	80.91	out/IECDLC1p3ETM_yaw-25_14mps_seed11.out
IECDLC1p4ECD	56.51	76.28	out/IECDLC1p4ECD_yaw-10_ECD+R+2.0.out
IECDLC1p5EWS	50.08	67.61	out/IECDLC1p5EWS_yaw40_EWSV+20.0.out
IECDLC6p1EWM50	14.16	19.12	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	155.05	170.55	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p3EWM01	35.90	48.46	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	MinYawBrMxn	with Safety Factor	in File
IECDLC1p2NTM	-4.93	-6.66	out/IECDLC1p2NTM_yaw-35_5mps_seed10.out
IECDLC1p3ETM	-8.25	-11.14	out/IECDLC1p3ETM_yaw25_6mps_seed2.out
IECDLC1p4ECD	-5.73	-7.73	out/IECDLC1p4ECD_yaw-35_ECD-R+2.0.out
IECDLC1p5EWS	-1.96	-2.65	out/IECDLC1p5EWS_yaw40_EWSV+5.0.out
IECDLC6p1EWM50	-117.83	-159.07	out/IECDLC6p1EWM50_EWM50-05.out
IECDLC6p2EWM50	-147.80	-162.58	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	-77.46	-104.57	out/IECDLC6p3EWM01_EWM01-05.out
DLC Name	MaxYawBrMyn	with Safety Factor	in File
IECDLC1p2NTM	106.74	144.10	out/IECDLC1p2NTM_yaw-40_15mps_seed9.out
IECDLC1p3ETM	122.34	165.16	out/IECDLC1p3ETM_yaw-40_15mps_seed9.out
IECDLC1p4ECD	105.69	142.68	out/IECDLC1p4ECD_yaw-15_ECD+R+2.0.out
IECDLC1p5EWS	82.83	111.82	out/IECDLC1p5EWS_yaw30_EWSV+20.0.out
IECDLC6p1EWM50	9.87	13.33	out/IECDLC6p1EWM50_EWM50+00.out
IECDLC6p2EWM50	11.87	13.06	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	7.96	10.74	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	MinYawBrMyn	with Safety Factor	in File
IECDLC1p2NTM	-51.89	-70.06	out/IECDLC1p2NTM_yaw-25_15mps_seed10.out
IECDLC1p3ETM	-77.26	-104.30	out/IECDLC1p3ETM_yaw-25_15mps_seed10.out
IECDLC1p4ECD	-177.31	-239.37	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	-52.20	-70.47	out/IECDLC1p5EWS_yaw-30_EWSV-20.0.out
IECDLC6p1EWM50	-45.46	-61.36	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	-36.25	-39.87	out/IECDLC6p2EWM50_EWM50+80.out
IECDLC6p3EWM01	-41.80	-56.43	out/IECDLC6p3EWM01_EWM01+20.out
DLC Name	AmplYawBrMxnMyn	with Safety Factor	in File
IECDLC1p2NTM	113.00	152.55	out/IECDLC1p2NTM_yaw-40_15mps_seed9.out
IECDLC1p3ETM	127.71	172.41	out/IECDLC1p3ETM_yaw-40_15mps_seed9.out
IECDLC1p4ECD	178.48	240.95	out/IECDLC1p4ECD_yaw-40_ECD-R.out
IECDLC1p5EWS	96.11	129.75	out/IECDLC1p5EWS_yaw30_EWSV+20.0.out
IECDLC6p1EWM50	117.98	159.27	out/IECDLC6p1EWM50_EWM50-05.out
IECDLC6p2EWM50	158.73	174.61	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p3EWM01	77.46	104.57	out/IECDLC6p3EWM01_EWM01-05.out

Baseline Case: -18:2:18 deg yaw, 5:1:25 m/s, 12 turbulent seeds, Class III-C

DLC Name	MaxYawBrMxn	with Safety Factor	in File
IECDLC1p2NTM	74.21	100.19	out/IECDLC1p2NTM_yaw18_25mps_seed7.out
IECDLC1p3ETM	82.69	111.63	out/IECDLC1p3ETM_yaw16_25mps_seed3.out
IECDLC1p4ECD	56.51	76.28	out/IECDLC1p4ECD_yaw-10_ECD+R+2.0.out
IECDLC1p5EWS	48.05	64.87	out/IECDLC1p5EWS_yaw18_EWSV+20.0.out
IECDLC6p1EWM50	14.16	19.12	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	155.05	170.55	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p3EWM01	35.90	48.46	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	MinYawBrMxn	with Safety Factor	in File
IECDLC1p2NTM	-4.76	-6.42	out/IECDLC1p2NTM_yaw14_5mps_seed10.out
IECDLC1p3ETM	-8.26	-11.15	out/IECDLC1p3ETM_yaw-16_6mps_seed2.out
IECDLC1p4ECD	-5.34	-7.21	out/IECDLC1p4ECD_yaw-8_ECD-R-2.0.out
IECDLC1p5EWS	0.11	0.14	out/IECDLC1p5EWS_yaw18_EWSV-5.0.out
IECDLC6p1EWM50	-117.83	-159.07	out/IECDLC6p1EWM50_EWM50-05.out
IECDLC6p2EWM50	-147.80	-162.58	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	-77.46	-104.57	out/IECDLC6p3EWM01_EWM01-05.out
DLC Name	MaxYawBrMyn	with Safety Factor	in File
IECDLC1p2NTM	137.69	185.88	out/IECDLC1p2NTM_yaw18_25mps_seed7.out
IECDLC1p3ETM	147.58	199.23	out/IECDLC1p3ETM_yaw18_25mps_seed10.out
IECDLC1p4ECD	105.70	142.70	out/IECDLC1p4ECD_yaw-16_ECD+R+2.0.out
IECDLC1p5EWS	79.10	106.79	out/IECDLC1p5EWS_yaw18_EWSV+20.0.out
IECDLC6p1EWM50	9.87	13.33	out/IECDLC6p1EWM50_EWM50+00.out
IECDLC6p2EWM50	11.87	13.06	out/IECDLC6p2EWM50_EWM50-80.out
IECDLC6p3EWM01	7.96	10.74	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	MinYawBrMyn	with Safety Factor	in File
IECDLC1p2NTM	-100.41	-135.55	out/IECDLC1p2NTM_yaw-18_25mps_seed9.out
IECDLC1p3ETM	-113.61	-153.37	out/IECDLC1p3ETM_yaw-18_25mps_seed5.out
IECDLC1p4ECD	-111.81	-150.94	out/IECDLC1p4ECD_yaw-18_ECD-R-2.0.out
IECDLC1p5EWS	-48.59	-65.60	out/IECDLC1p5EWS_yaw-18_EWSV-20.0.out
IECDLC6p1EWM50	-45.46	-61.36	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	-36.25	-39.87	out/IECDLC6p2EWM50_EWM50+80.out
IECDLC6p3EWM01	-41.80	-56.43	out/IECDLC6p3EWM01_EWM01+20.out
DLC Name	AmplYawBrMxnMyn	with Safety Factor	in File
IECDLC1p2NTM	153.19	206.80	out/IECDLC1p2NTM_yaw16_24mps_seed2.out
IECDLC1p3ETM	163.36	220.54	out/IECDLC1p3ETM_yaw18_25mps_seed3.out
IECDLC1p4ECD	118.20	159.56	out/IECDLC1p4ECD_yaw-16_ECD+R+2.0.out
IECDLC1p5EWS	91.77	123.89	out/IECDLC1p5EWS_yaw18_EWSV+20.0.out
IECDLC6p1EWM50	117.98	159.27	out/IECDLC6p1EWM50_EWM50-05.out
IECDLC6p2EWM50	158.73	174.61	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p3EWM01	77.46	104.57	out/IECDLC6p3EWM01_EWM01-05.out

Nacelle Overturning Moment

Yawed Case 3: -40:5:40 deg yaw, 5:1:15 m/s, yaw controller, 12 turbulent seeds, Class III-C

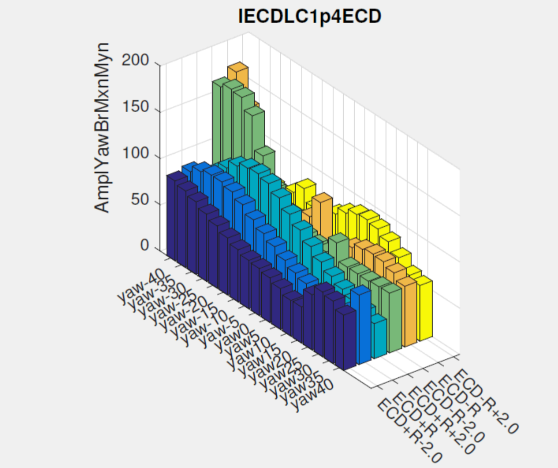
DLC Name	MaxYawBrMxn	with Safety Factor	in File
IECDLC1p2NTM	54.12	73.06	out/IECDLC1p2NTM_yaw-35_15mps_seed11.out
IECDLC1p3ETM	59.94	80.91	out/IECDLC1p3ETM_yaw-25_14mps_seed11.out
IECDLC1p4ECD	56.51	76.28	out/IECDLC1p4ECD_yaw-10_ECD+R+2.0.out
IECDLC1p5EWS	50.08	67.61	out/IECDLC1p5EWS_yaw40_EWSV+20.0.out
IECDLC6p1EWM50	14.16	19.12	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	155.05	170.55	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p3EWM01	35.90	48.46	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	MinYawBrMxn	with Safety Factor	in File
IECDLC1p2NTM	-4.93	-6.66	out/IECDLC1p2NTM_yaw-35_5mps_seed10.out
IECDLC1p3ETM	-8.25	-11.14	
IECDLC1p4ECD	-5.73	-7.73	
IECDLC1p5EWS	-1.96	-2.65	
IECDLC6p1EWM50	-117.83	-159.07	
IECDLC6p2EWM50	-147.80	-162.58	
IECDLC6p3EWM01	-77.46	-104.57	
DLC Name	MaxYawBrMyn	with Safety Facto	
IECDLC1p2NTM	106.74	144.10	
IECDLC1p3ETM	122.34	165.16	
IECDLC1p4ECD	105.69	142.68	
IECDLC1p5EWS	82.83	111.82	
IECDLC6p1EWM50	9.87	13.33	
IECDLC6p2EWM50	11.87	13.06	
IECDLC6p3EWM01	7.96	10.74	
DLC Name	MinYawBrMyn	with Safety Facto	
IECDLC1p2NTM	-51.89	-70.06	
IECDLC1p3ETM	-77.26	-104.30	
IECDLC1p4ECD	-177.31	-239.37	
IECDLC1p5EWS	-52.20	-70.47	
IECDLC6p1EWM50	-45.46	-61.36	
IECDLC6p2EWM50	-36.25	-39.87	
IECDLC6p3EWM01	-41.80	-56.43	
DLC Name	AmplYawBrMxnMyn	with Safety Facto	
IECDLC1p2NTM	113.00	152.55	
IECDLC1p3ETM	127.71	172.41	
IECDLC1p4ECD	178.48	240.95	
IECDLC1p5EWS	96.11	129.75	
IECDLC6p1EWM50	117.98	159.27	out/IECDLC6p1EWM50_EWM50-05.out
IECDLC6p2EWM50	158.73	174.61	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p3EWM01	77.46	104.57	out/IECDLC6p3EWM01_EWM01-05.out

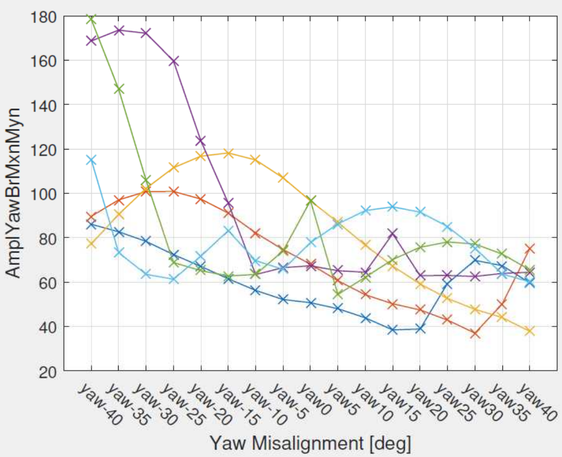
Baseline Case: -18:2:18 deg yaw, 5:1:25 m/s, 12 turbulent seeds, Class III-C

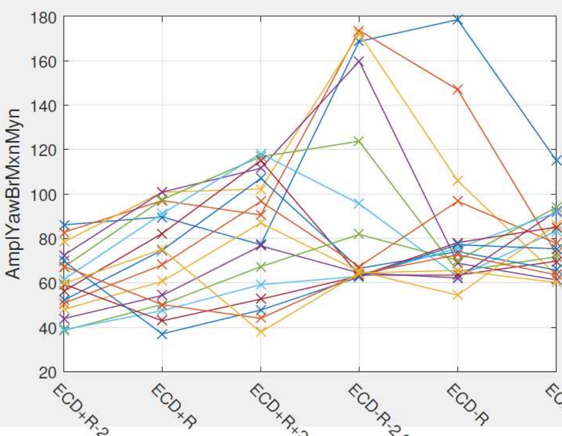
DLC Name	MaxYawBrMxn	with Safety Factor	in File
IECDLC1p2NTM	74.21	100.19	out/IECDLC1p2NTM_yaw18_25mps_seed7.out
IECDLC1p3ETM	82.69	111.63	out/IECDLC1p3ETM_yaw16_25mps_seed3.out
IECDLC1p4ECD	56.51	76.28	out/IECDLC1p4ECD_yaw-10_ECD+R+2.0.out
IECDLC1p5EWS	48.05	64.87	out/IECDLC1p5EWS_yaw18_EWSV+20.0.out
IECDLC6p1EWM50	14.16	19.12	out/IECDLC6p1EWM50_EWM50+15.out
IECDLC6p2EWM50	155.05	170.55	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p3EWM01	35.90	48.46	out/IECDLC6p3EWM01_EWM01-30.out
DLC Name	MinYawBrMxn	with Safety Factor	in File
IECDLC1p2NTM	-4.76	-6.42	out/IECDLC1p2NTM_yaw14_5mps_seed10.out
	.26	-11.15	out/IECDLC1p3ETM_yaw-16_6mps_seed2.out
	.34	-7.21	out/IECDLC1p4ECD_yaw-8_ECD-R-2.0.out
	.11	0.14	out/IECDLC1p5EWS_yaw18_EWSV-5.0.out
	7.83	-159.07	out/IECDLC6p1EWM50_EWM50-05.out
	7.80	-162.58	out/IECDLC6p2EWM50_EWM50-80.out
	7.46	-104.57	out/IECDLC6p3EWM01_EWM01-05.out
	wBrMyn	with Safety Factor	in File
	7.69	185.88	out/IECDLC1p2NTM_yaw18_25mps_seed7.out
	7.58	199.23	out/IECDLC1p3ETM_yaw18_25mps_seed10.out
	5.70	142.70	out/IECDLC1p4ECD_yaw-16_ECD+R+2.0.out
	.10	106.79	out/IECDLC1p5EWS_yaw18_EWSV+20.0.out
	.87	13.33	out/IECDLC6p1EWM50_EWM50+00.out
	.87	13.06	out/IECDLC6p2EWM50_EWM50-80.out
	.96	10.74	out/IECDLC6p3EWM01_EWM01-30.out
	wBrMyn	with Safety Factor	in File
	0.41	-135.55	out/IECDLC1p2NTM_yaw-18_25mps_seed9.out
	3.61	-153.37	out/IECDLC1p3ETM_yaw-18_25mps_seed5.out
	1.81	-150.94	out/IECDLC1p4ECD_yaw-18_ECD-R-2.0.out
	3.59	-65.60	out/IECDLC1p5EWS_yaw-18_EWSV-20.0.out
	5.46	-61.36	out/IECDLC6p1EWM50_EWM50+15.out
	5.25	-39.87	out/IECDLC6p2EWM50_EWM50+80.out
	1.80	-56.43	out/IECDLC6p3EWM01_EWM01+20.out
	BrMxnMyn	with Safety Factor	in File
	3.19	206.80	out/IECDLC1p2NTM_yaw16_24mps_seed2.out
	3.36	220.54	out/IECDLC1p3ETM_yaw18_25mps_seed3.out
	8.20	159.56	out/IECDLC1p4ECD_yaw-16_ECD+R+2.0.out
	.77	123.89	out/IECDLC1p5EWS_yaw18_EWSV+20.0.out
IECDLC6p1EWM50	117.98	159.27	out/IECDLC6p1EWM50_EWM50-05.out
IECDLC6p2EWM50	158.73	174.61	out/IECDLC6p2EWM50_EWM50+95.out
IECDLC6p3EWM01	77.46	104.57	out/IECDLC6p3EWM01_EWM01-05.out

If not considering DLC 1.4, the maximum amplitude for yaw overturning moment for Yawed Case 3 is less than for the Baseline Case.

- A control is needed to ensure that there is never an operational negative thrust produced by the rotor
- (as seen later) this alarm should not activate rapidly, or it may increase the loads







Maximum Nacelle Overturning Moment Magnitude, Characteristic Loads:

- Baseline: 163.4 kNm
- Est. Strength: unknown

To not exceed the baseline, either:

(1) Yaw errors cannot exceed -25-deg (negative, increasing magnitude)

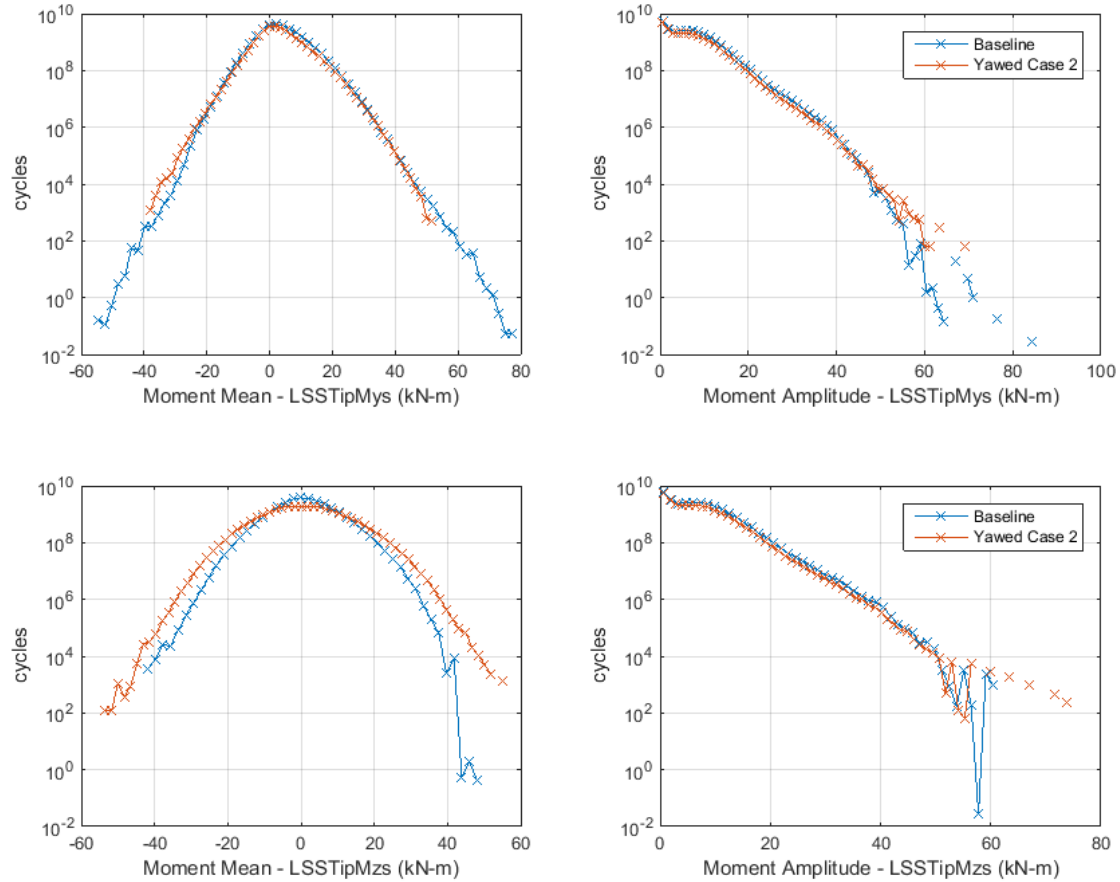
(2) Yaw errors in the (+) direction do not produce large nacelle overturning moments due to rotor moment being positive and counteracting the negative thrust moment

YAW MISALIGNMENT LOADS ANALYSIS – FATIGUE LOADS

Nacelle Overturning Moment

<u>DLC 1.2 Rainflow cycle counts</u>

- Performed using yawed case 2 and compared with the baseline case
- Counts are summed up probabilistically using the site Weibull wind speed distribution
- Shown for a 20 year life
- Wind directions are treated as equally probable



Fatigue Analysis

- Using Miner's Rule for 3 materials (performed for yawed case 2)
  - Uni-directional glass with epoxy laminate construction
  - Uni-directional carbon with epoxy matrix
  - Tri-axial glass with epoxy laminate construction

	E-LT-5500(UD)	Newport 307 Carbon Prepreg (UD)	SNL (Triax)
Baseline			
Yawed Case	1.9e-6	1.6e-5	3.7e-5

Backup Slides

Comparison with NREL results

YAW MISALIGNMENT LOADS ANALYSIS – ULTIMATE LOADS

DLC 1.1

- Values shown without safety factors
- Flap bending moment maximum is 142*1.35 = 191.7 kNm for yawed case
- Magnitude is lower than the DLC 1.3 value of 209.9 kNm
- DLC 1.1 is not a design driver for the yaw case (-40:5:40 deg)
  - DLC 1.1 is currently treating each yaw case as equally probable

Yaw Misalignments: -18:2:18, 12 seeds, 5:1:20 m/s						
Row	Fx	Fy	Fz	Mx	My	Mz
Root	15.65518	6.457395	82.19659	57.9515	118.5802	0.470297
Spn1	15.63585	6.152009	75.99393	29.45574	94.44348	0.41875
Spn2	14.53294	4.8895	68.48629	22.30246	74.92572	0.334324
Spn3	13.02861	4.018171	59.7821	17.53226	57.33028	0.386829
Spn4	11.21057	3.362086	50.68436	13.24283	41.55493	0.519982
Spn5	9.299749	2.833918	41.56548	9.362464	28.09574	0.636687
Spn6	7.235968	2.345248	32.21901	5.963352	17.24251	0.629413
Spn7	5.194278	1.828942	23.02035	3.233582	9.285987	0.562324
Spn8	3.296188	1.064411	13.78063	1.258772	3.805286	0.40023
Spn9	1.425777	0.38402	5.276465	0.214247	0.724139	0.173814

Yaw Misalignments: -40:5:40, 12 seeds, 5:1:20 m/s						
Row	Fx	Fy	Fz	Mx	My	Mz
Root	18.70022	6.725513	82.28198	66.43433	142.0602	0.621521
Spn1	19.48077	6.391973	76.06611	28.7317	118.7779	0.557812
Spn2	18.25562	5.199239	68.54885	22.73677	93.64218	0.492872
Spn3	16.4717	4.201338	59.83467	18.18887	70.48696	0.585927
Spn4	14.25391	3.422192	50.72288	14.10583	50.04462	0.769219
Spn5	11.72392	2.829432	41.77887	10.09156	32.87459	0.871409
Spn6	8.876219	2.269802	33.55098	6.569454	20.27323	0.777823
Spn7	6.138986	1.708075	22.87188	3.699964	10.94457	0.675952
Spn8	3.886575	1.003659	13.78838	1.515545	4.545802	0.450957
Spn9	1.715095	0.36919	5.274307	0.283215	0.867011	0.186482

Ratio: yaw/orig						
Row	Fx	Fy	Fz	Mx	My	Mz
Root	1.19	1.04	1.00	1.15	1.20	1.32
Spn1	1.25	1.04	1.00	0.98	1.26	1.33
Spn2	1.26	1.06	1.00	1.02	1.25	1.47
Spn3	1.26	1.05	1.00	1.04	1.23	1.51
Spn4	1.27	1.02	1.00	1.07	1.20	1.48
Spn5	1.26	1.00	1.01	1.08	1.17	1.37
Spn6	1.23	0.97	1.04	1.10	1.18	1.24
Spn7	1.18	0.93	0.99	1.14	1.18	1.20
Spn8	1.18	0.94	1.00	1.20	1.19	1.13
Spn9	1.20	0.96	1.00	1.32	1.20	1.07

NREL Results

Load direction	Coordinate	Allowable Ultimate Design Loads (Romax)	-30	-18	Baseline	18	30
Blade root pitching	$Mz_{b,i}$	? kNm	3.86	3.2	3.27	3.14	4.1
LSS bending	$\lvert My_s + Mz_s \rvert$	9 kNm	175	138	110	172	196
LSS torque	Mx_s	55 kNm	77	73	74	72	75
Tower base bending	$\lvert Mx_n + My_n \rvert$	? kN	1698	2083	1970	1929	1352
Tower top acceleration	$\lvert A_x + A_y \rvert$	m/s2	3.79	2.87	2.61	2.75	2.19

Load (with IEC FS)	Variable	-30 yaw	-20 yaw	0 yaw	20 yaw	30 yaw
Blade Root Bending	|Mx,b1 + My,b1|	200.3	192.1	186.5	186.5	187.5
	|Mx,b2 + My,b2|	203.5	194.0	172.2	186.6	187.4
	|Mx,b3 + My,b3|	203.1	182.7	168.0	167.6	187.5
Nacelle Yaw Moment	max(Mz,n)	119.0	111.1	93.6	96.0	99.2
	min(Mz,n)	-111.6	-105.0	-101.2	-118.0	-125.9

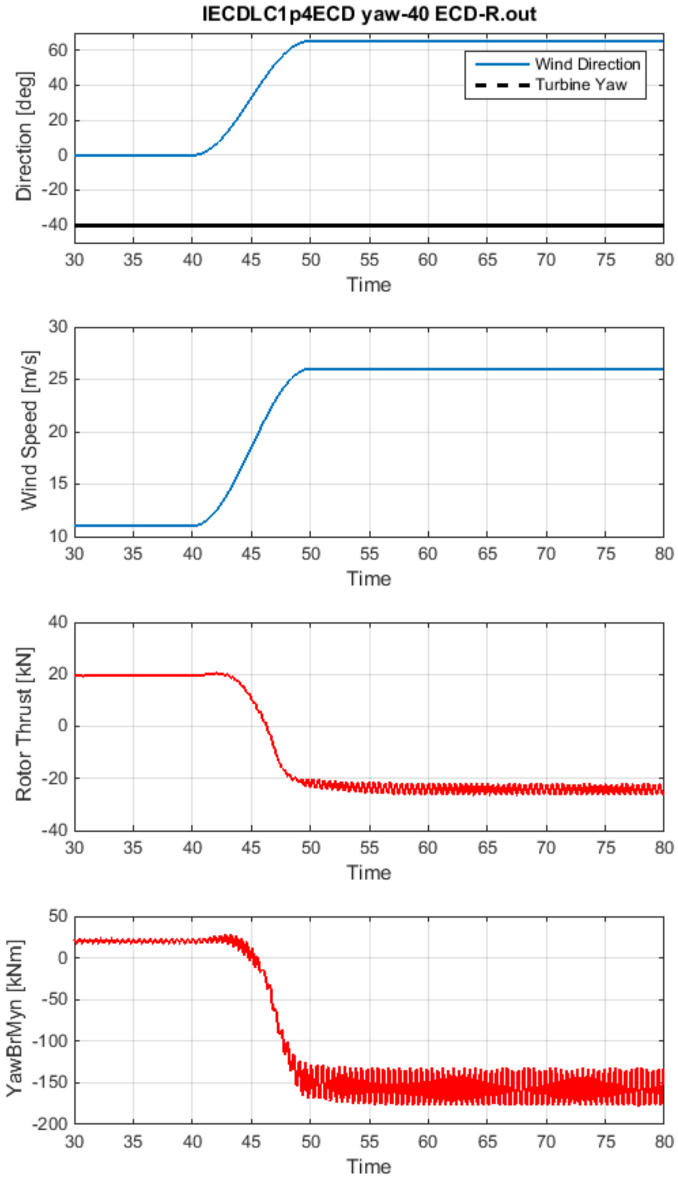
Conclusion:
The DLC 1.4 case with high yaw error produces negative angles of attack for the airfoils which then produce the negative thrust while operating at a positive torque contribution and operational rotation.

Positive yaw directions are not of concern for the nacelle overturning moment.

**Yawed Case 2 Loads

EXPLANATION OF DLC 1.4 LOADS

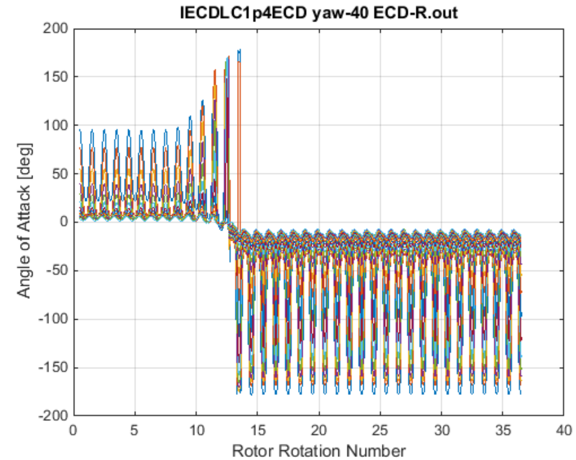
Nacelle Overturning Moment



(1) Wind direction shifts to come from 105 deg relative to rotor front. (wind from 15 deg behind the rotor plane of rotation)

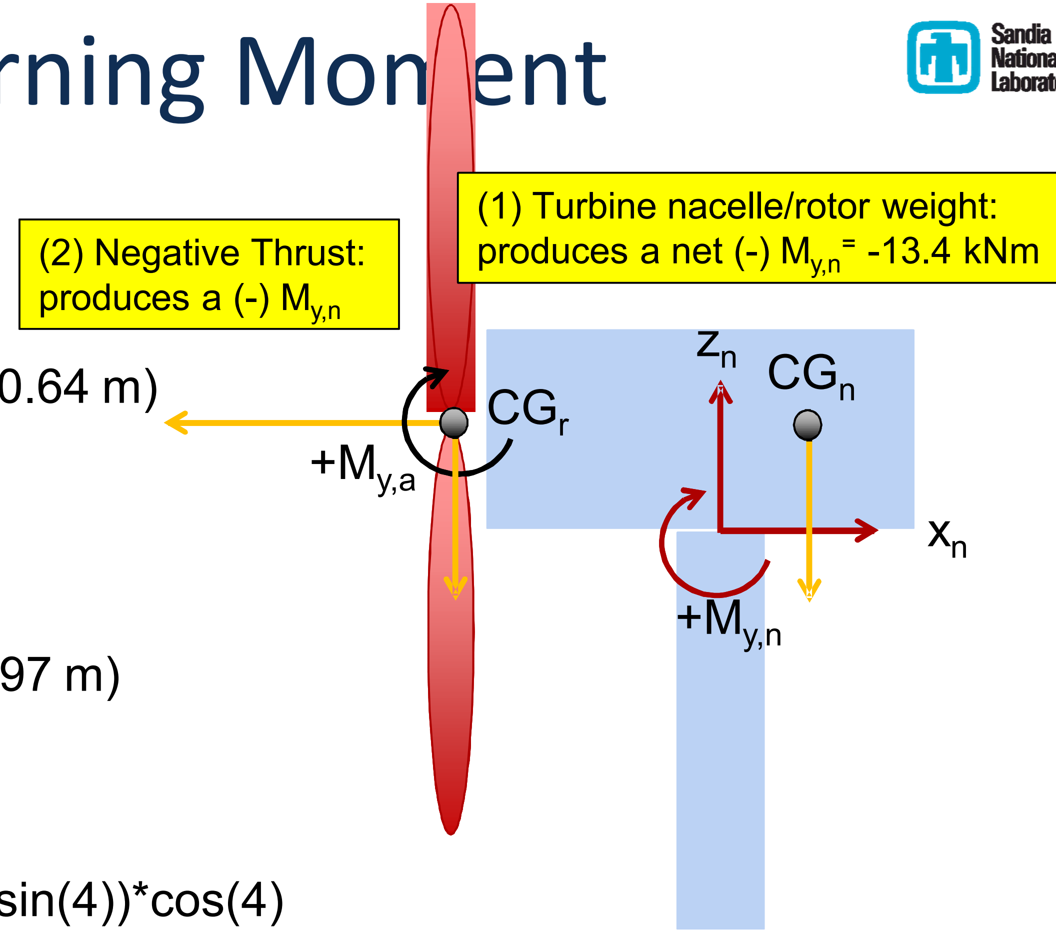
(2) Wind speed increase to 26 m/s (U_{normal} changes from $U_{n,1}$=8.43 m/s to $U_{n,2}$=-6.72 m/s)

(3) Element Angle of Attack changes to (-) values with a lift that produces a (-) thrust value



(4) Negative thrust now adds to the negative CG moment of the nacelle/rotor creating a disproportionately larger overturning moment (M_{yn})

Nacelle Overturning Moment



CG_n:

$M_{yn,nac} = (6909.5\ kg)*(9.81\ m/s^2)*(0.64\ m)$
$= 43.4$ kN-m

CG_r:

$m_r = 1165 + 3*590.6 = 2937$ kg

$M_{yn,rot} = -(2937\ kg)*(9.81\ m/s^2)*(1.97\ m)$
$= -56.8$ kN-m

Thrust:

$M_{yn,thrust} = -(24\ kN)*(1.5+(1.88\ m)*\sin(4))*\cos(4)$
$= -39.1$ kN-m

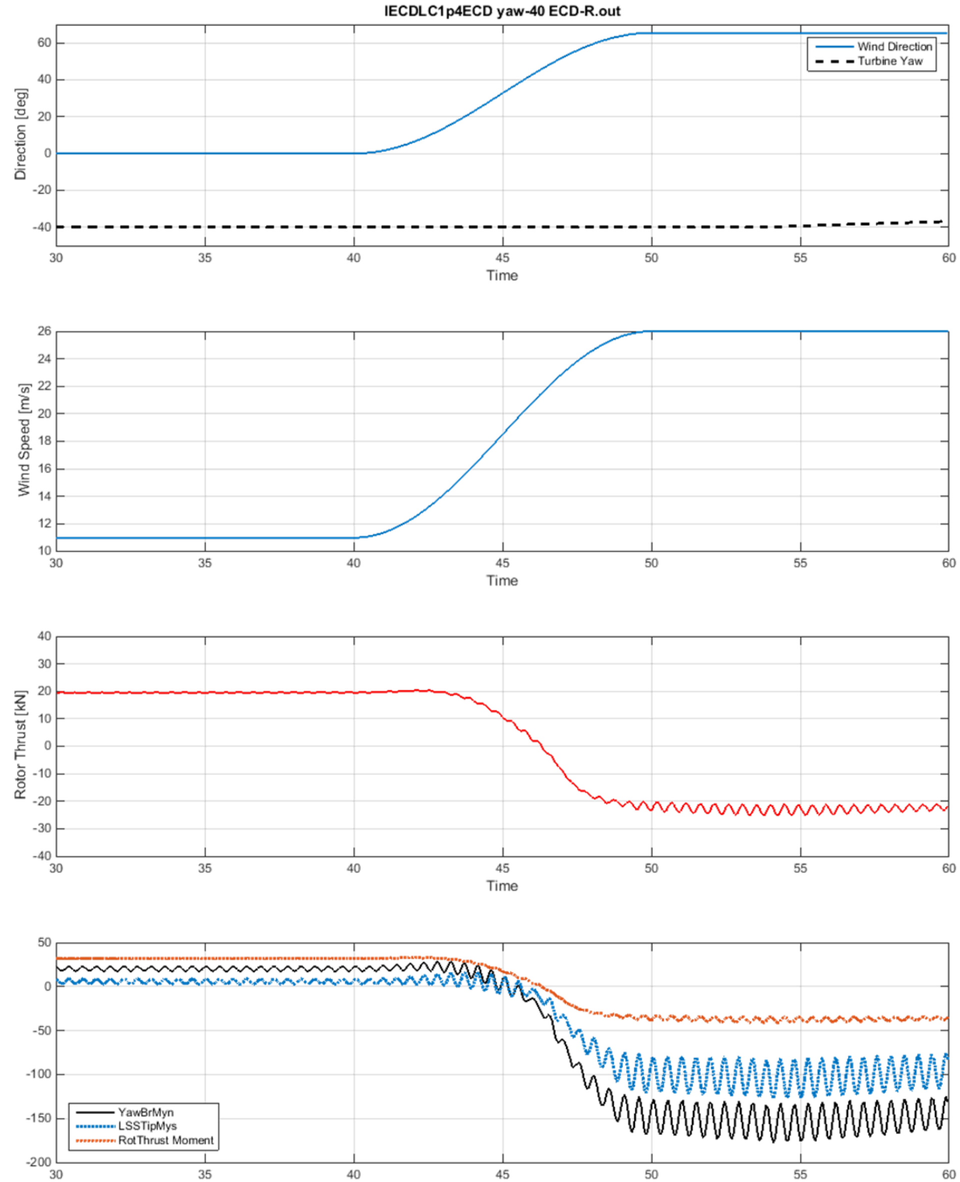
$M_{ya,thrust} = -120$ kN-m

Estimated My,n for DLC 1.4 case: My,n = -172.5 kNm

Estimated My,n is less than the maximum amplitude (178 kNm) value for the DLC 1.4 case
- Explained by inertial effects

Nacelle Overturning Moment

Nacelle Overturning Moment Source:



(1) Wind direction shifts to come from 105 deg relative to rotor front producing a negative thrust (wind from 15 deg behind the rotor plane of rotation)

(2) Wind Shear (\alpha = 0.14) means top half of the rotor sees higher velocities and has higher forces, producing a rotor Mys moment

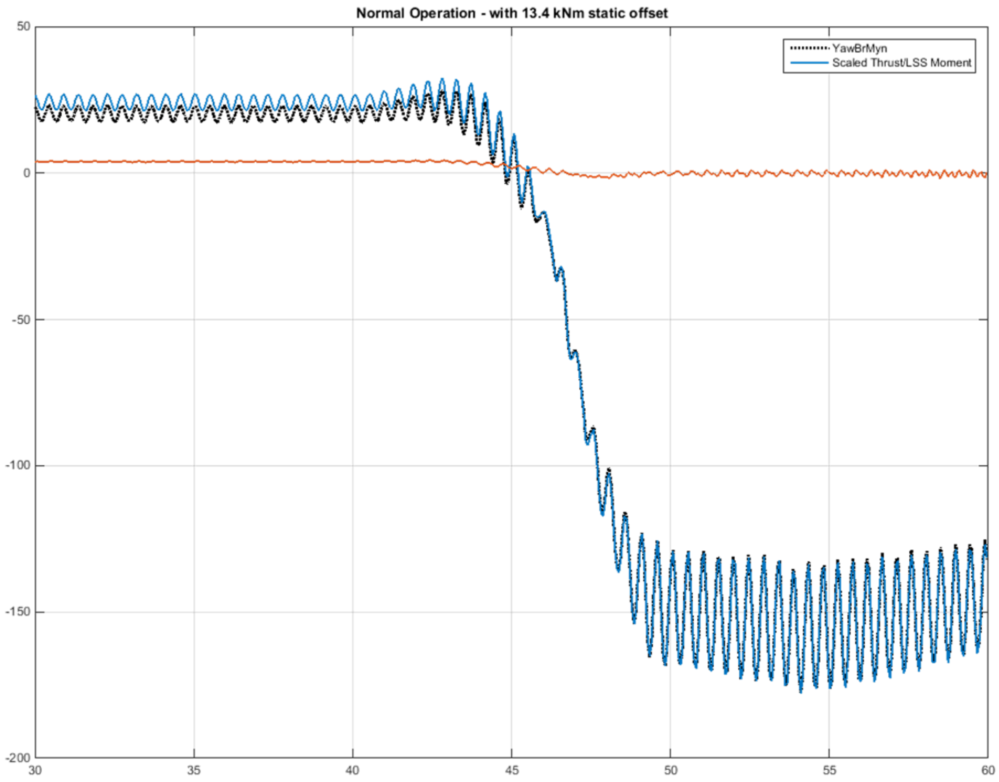
(3) Static moment balance is -13.4 kNm from nacelle and rotor mass

Nacelle Overturning Moment

Nacelle Overturning Moment Source:

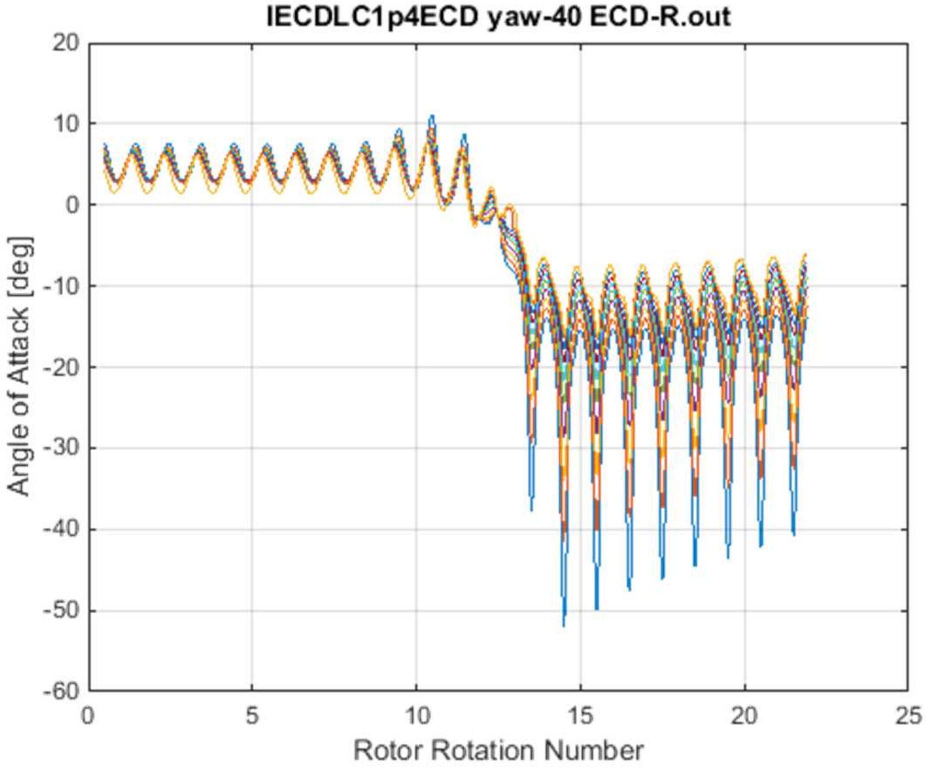
The combination of (1) rotor thrust produced moment, (2) rotor axis moment due to shear and (3) the static CG moment nearly reproduce the nacelle overturning moment

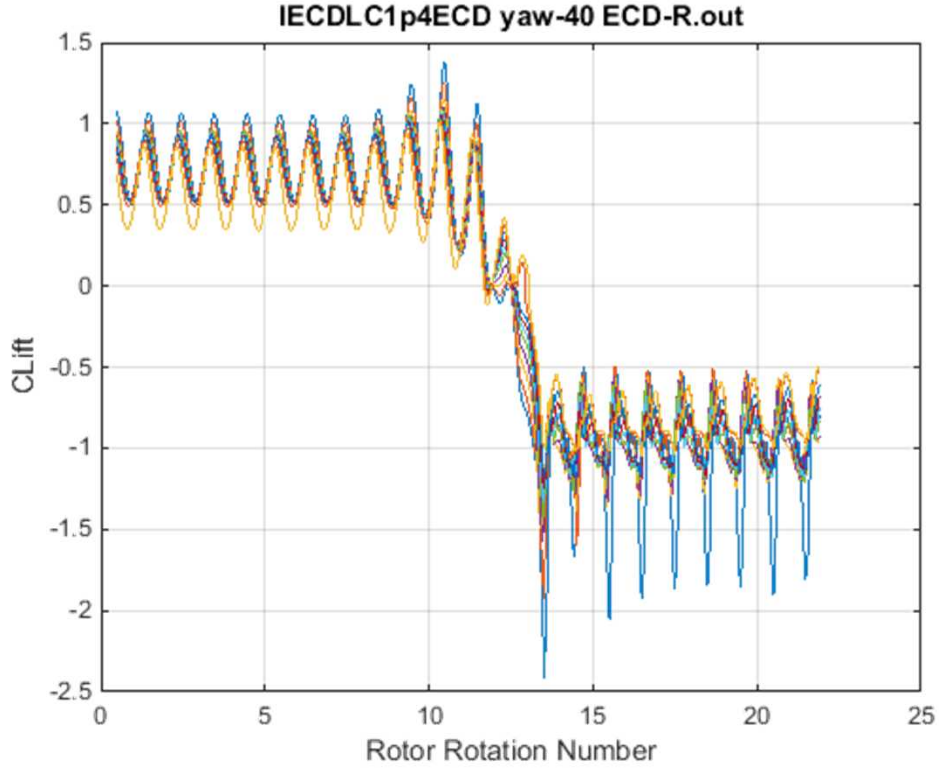
There is a small (~5 kNm) discrepancy that moves towards 0 when the thrust crosses 0 (wind direction switches to be from behind the rotor) – could be inertial effects between the nacelle and tower not seen in the rotor thrust/moment



Nacelle Overturning Moment

Nacelle Overturning Moment Source:

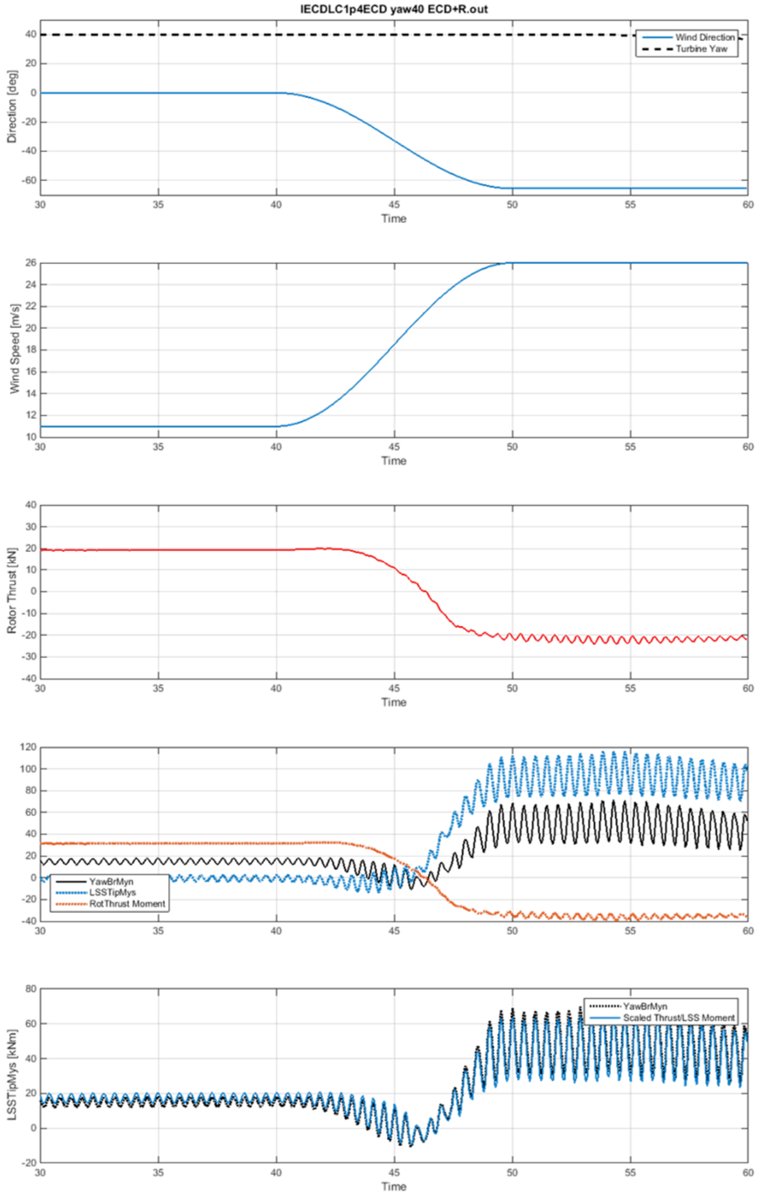




Nacelle Overturning Moment

Nacelle Overturning Moment Source:

+40 deg yaw
ECD+R wind direction shift

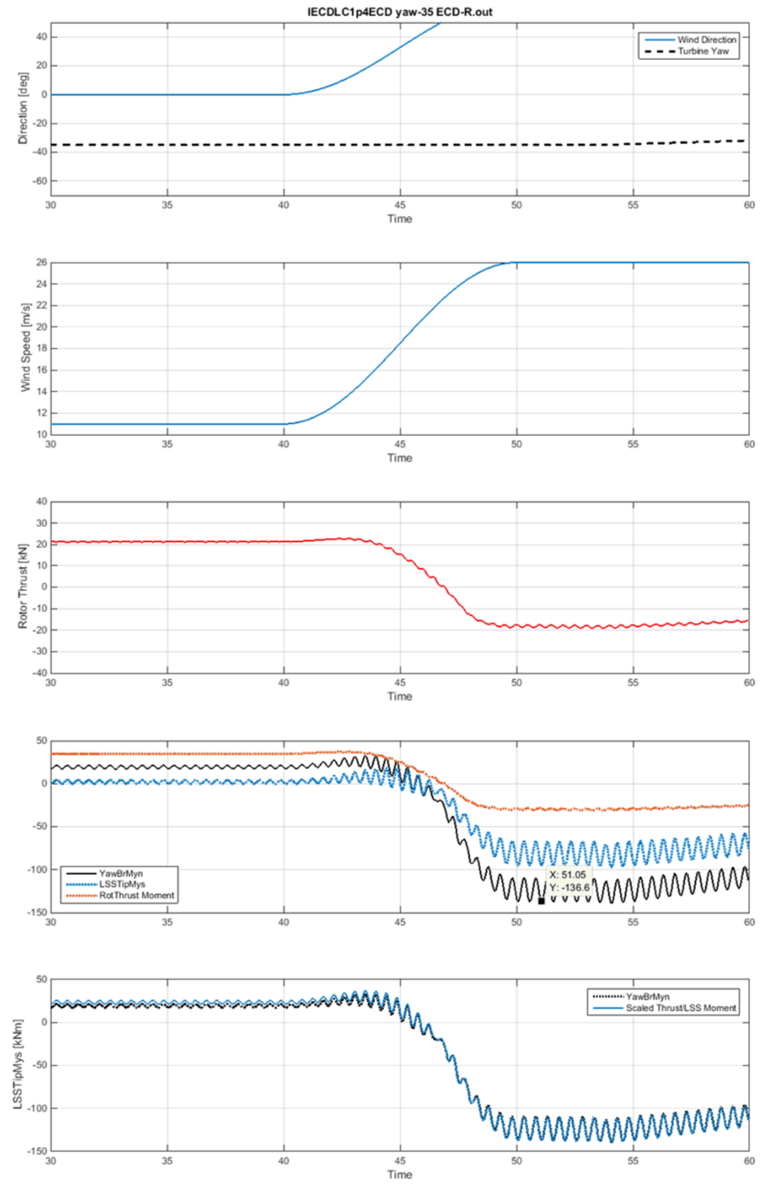


Positive yaw directions are not of concern because the rotor moment is positive due to the advance on the bottom half of the rotor plane (where velocities are lower due to wind shear)

Nacelle Overturning Moment

Nacelle Overturning Moment Source:

-35 deg yaw
ECD-R wind direction shift



-35 deg yaw error with the 1.4 wind case produces a net overturning moment that is beneath the design baseline value.

Conclusion:
The ‘fast’ yaw error alarm was tested and it was shown how this alarm (even when sending to PAUSE) can add to loads that were acceptable, making them unacceptable. The ‘fast’ yaw error alarm should be removed from the controller.

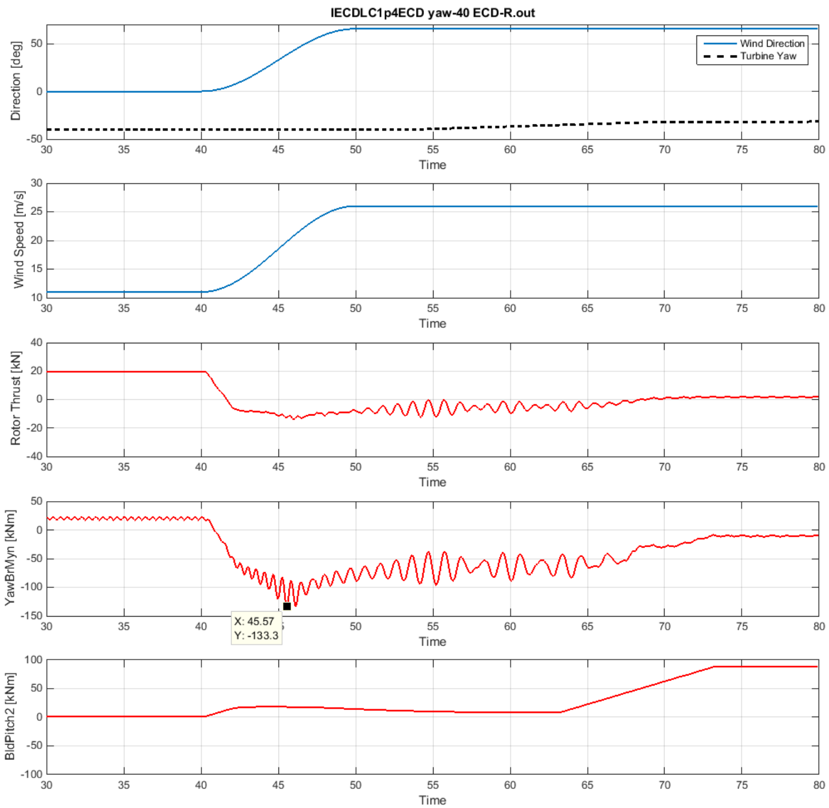
Yawed Case 2 Loads

ALARM ANALYSIS FOR DLC 1.4 LOADS MITIGATION

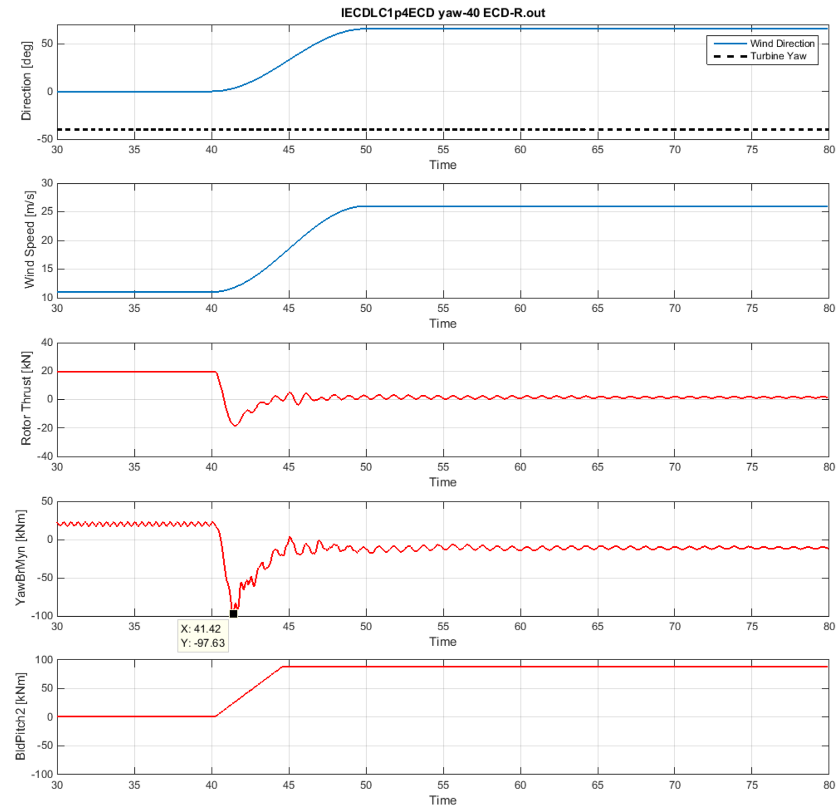
Nacelle Overturning Moment

0 deg “fast yaw error” limit (40 deg setting & -40 deg intentional yaw)

PAUSE alarm



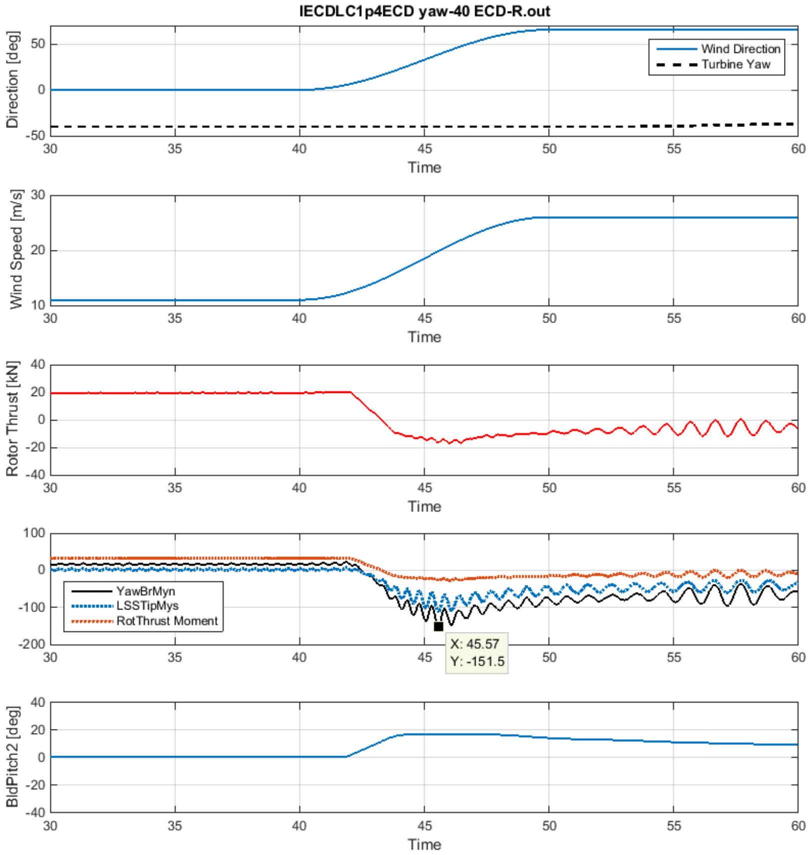
STOP alarm



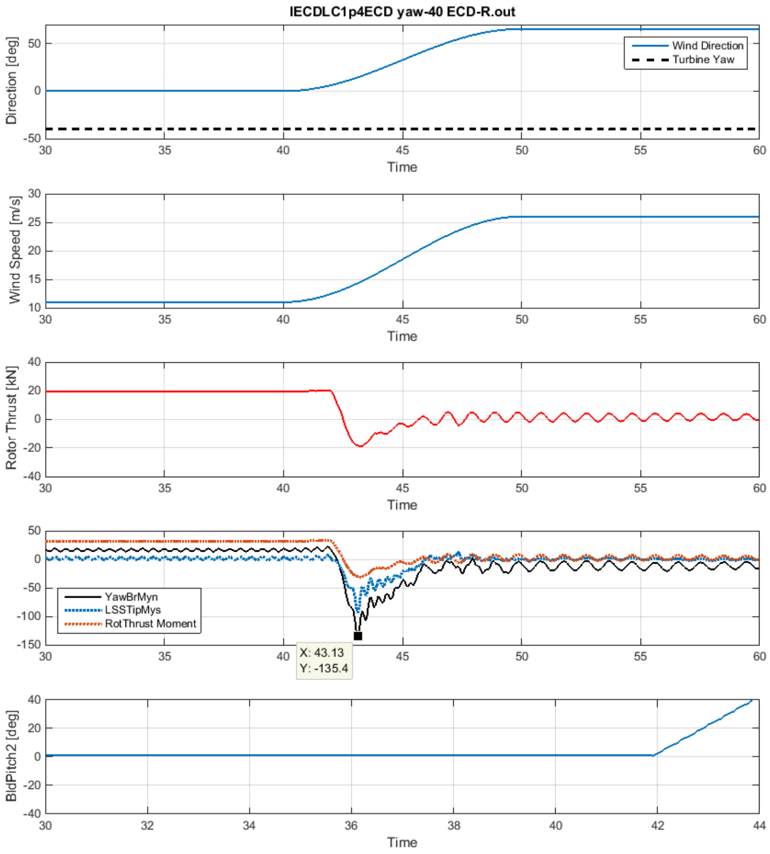
Nacelle Overturning Moment

5 deg “fast yaw error” limit (45 deg setting & -40 deg intentional yaw)

PAUSE alarm



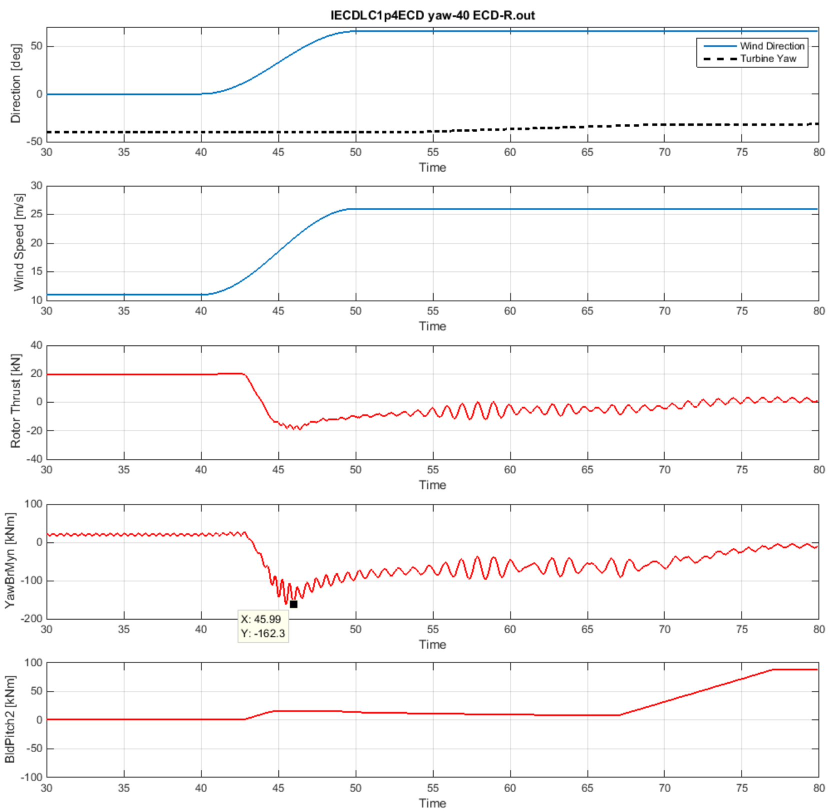
STOP alarm



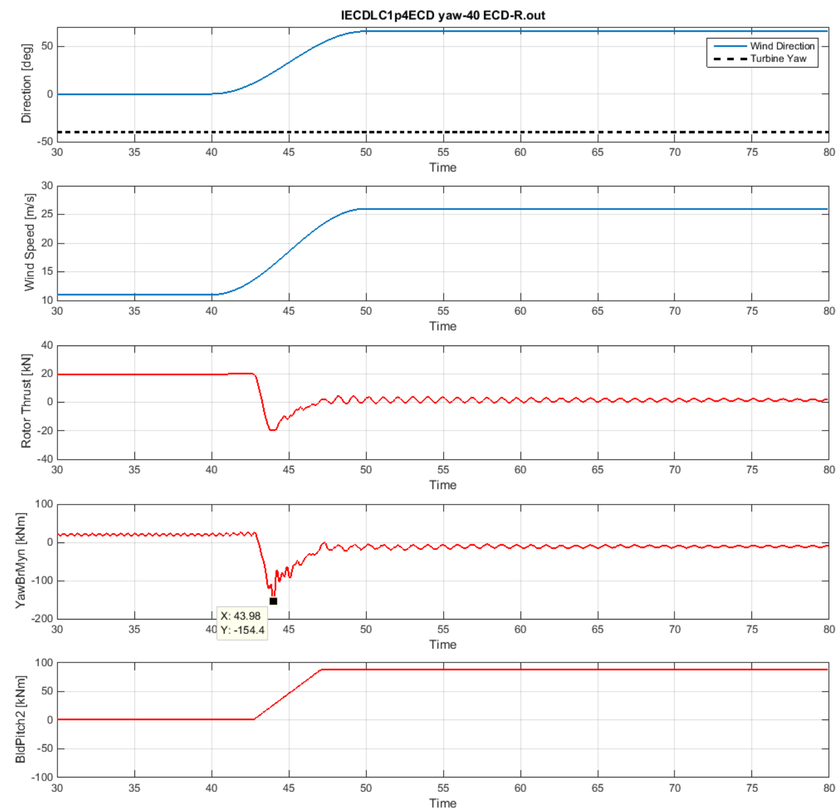
Nacelle Overturning Moment

10 deg “fast yaw error” limit (50 deg setting & -40 deg intentional yaw)

PAUSE alarm



STOP alarm

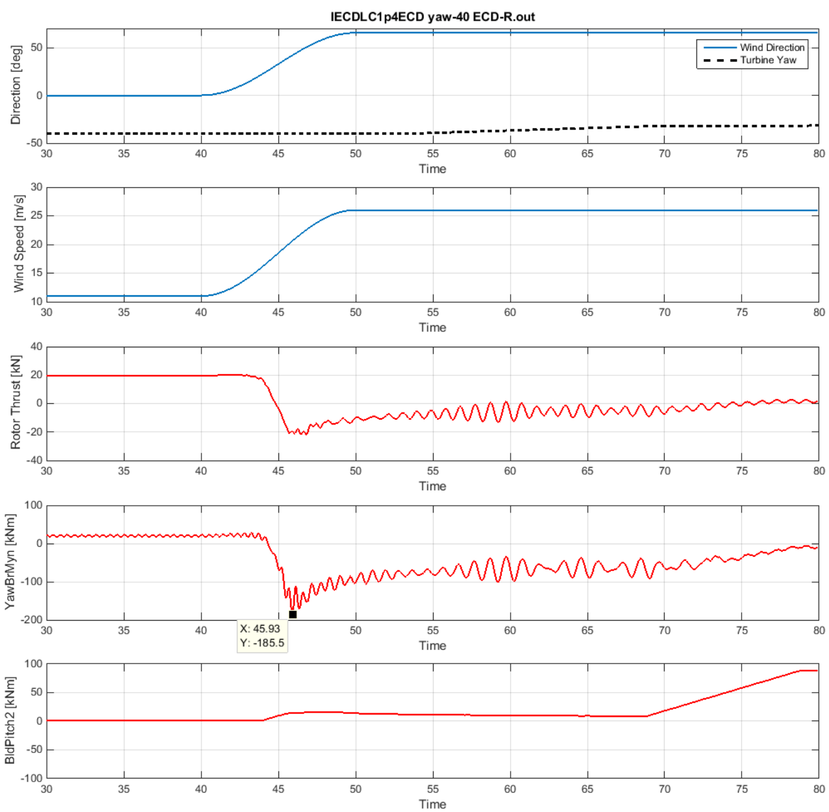


Nacelle Overturning Moment

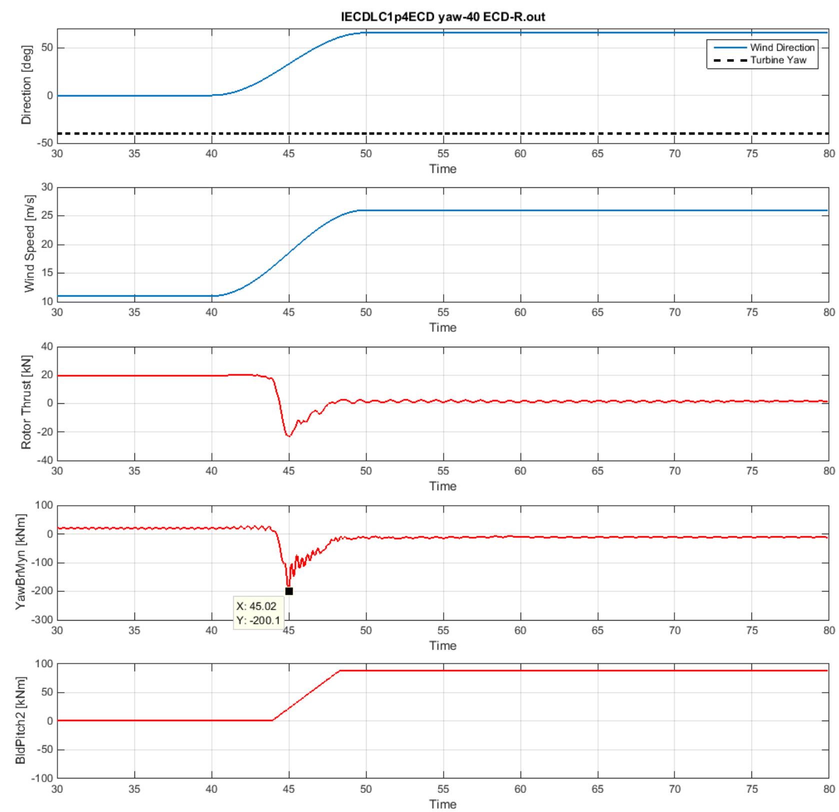
Sandia National Laboratories

20 deg “fast yaw error” limit (60 deg setting & -40 deg intentional yaw)

PAUSE alarm



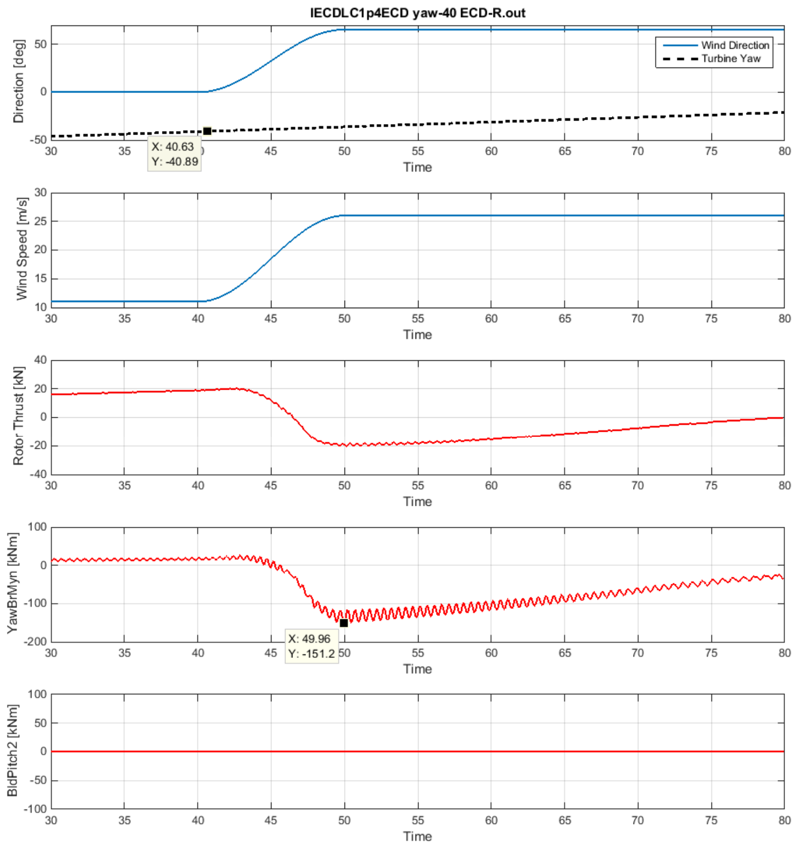
STOP alarm



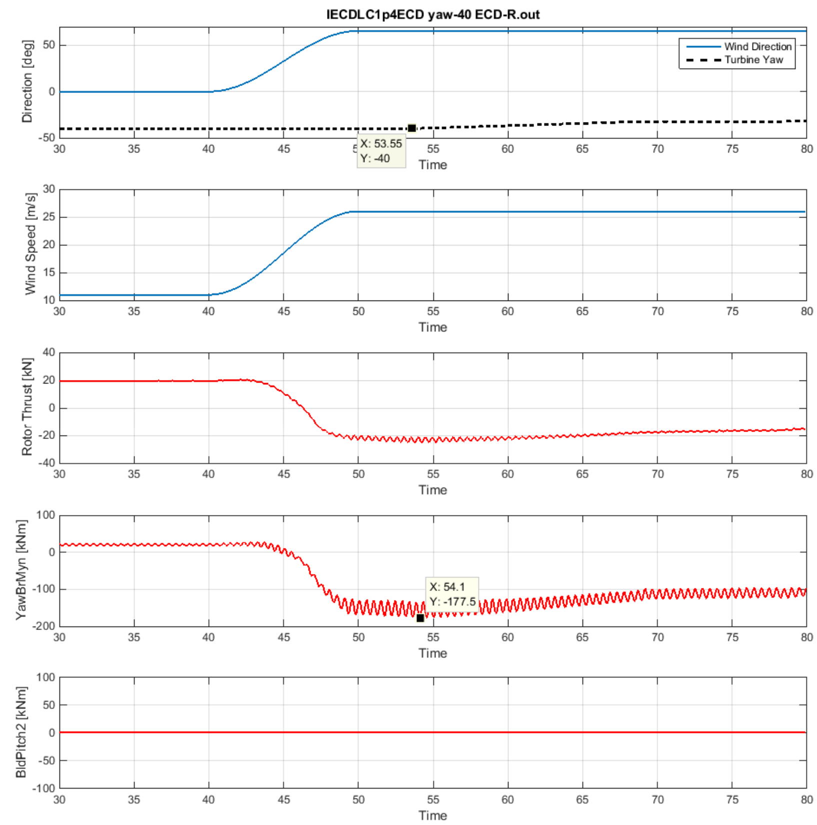
Nacelle Overturning Moment

20 deg “fast yaw error” limit (60 deg setting & -40 deg intentional yaw)

NO alarm; constant yawing



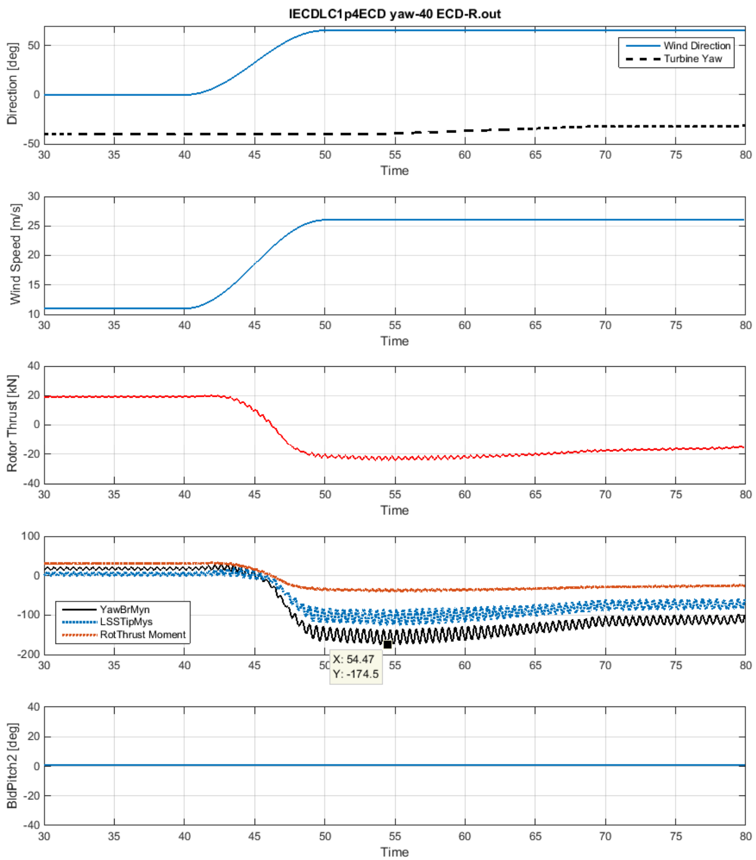
NO alarm; normal yawing



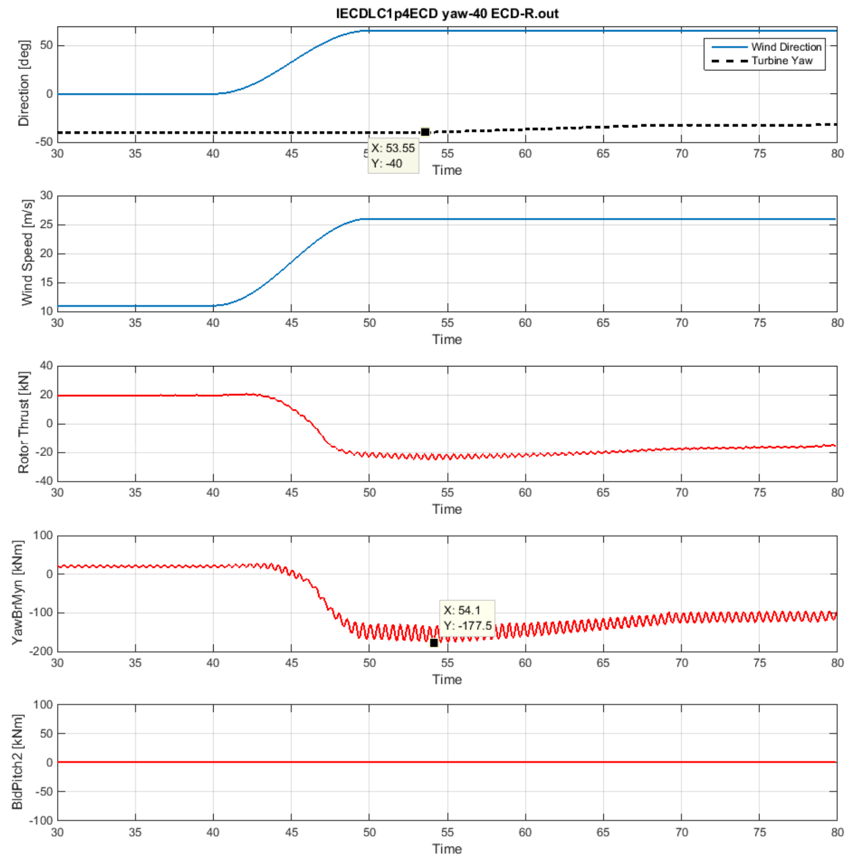
Nacelle Overturning Moment

Dynamic Stall Model test – produces the same magnitude moment.

NO DYNAMIC STALL MODEL



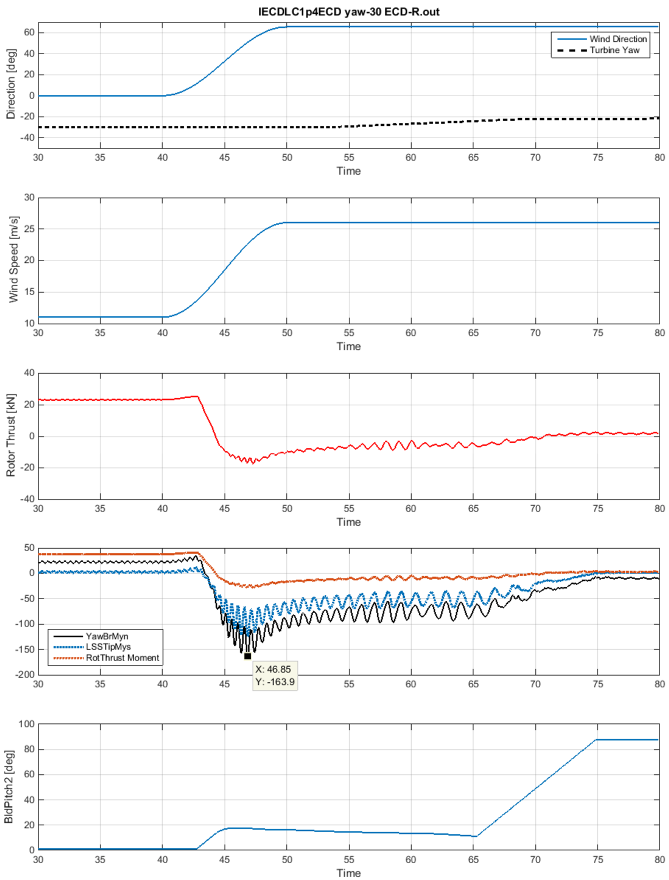
NO alarm; normal yawing



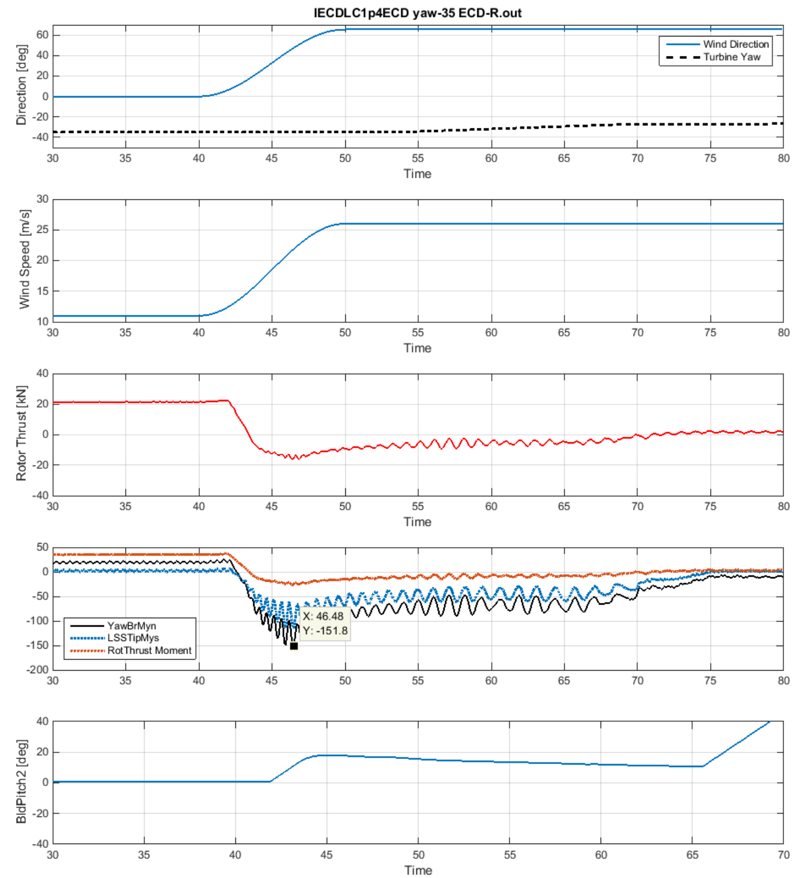
Nacelle Overturning Moment

Test max fast yaw error settings (40 deg setting)

PAUSE alarm; -30 deg yaw



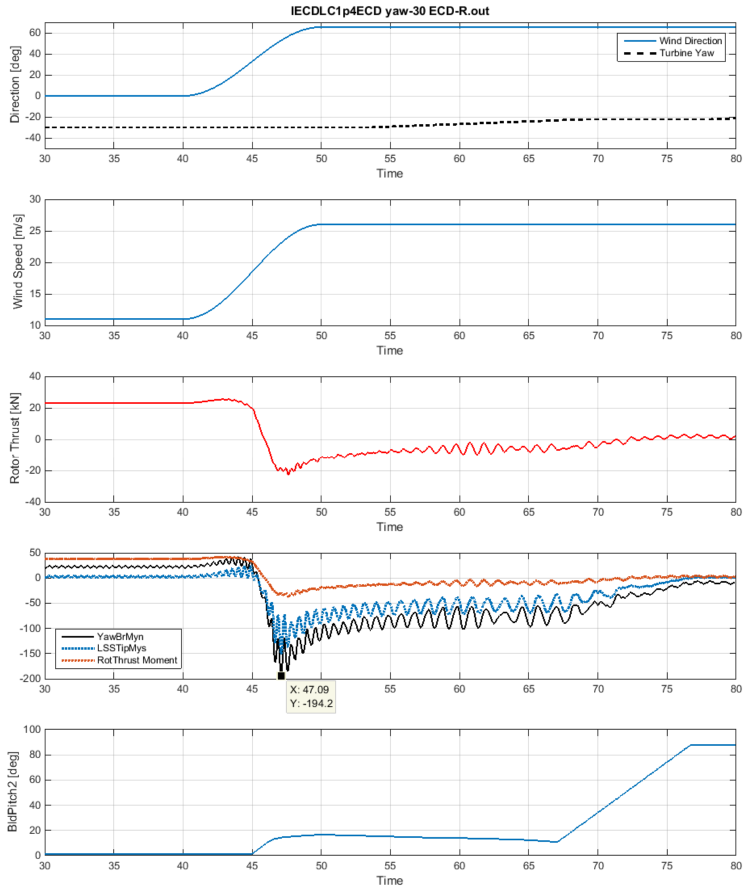
PAUSE alarm; -35 deg yaw



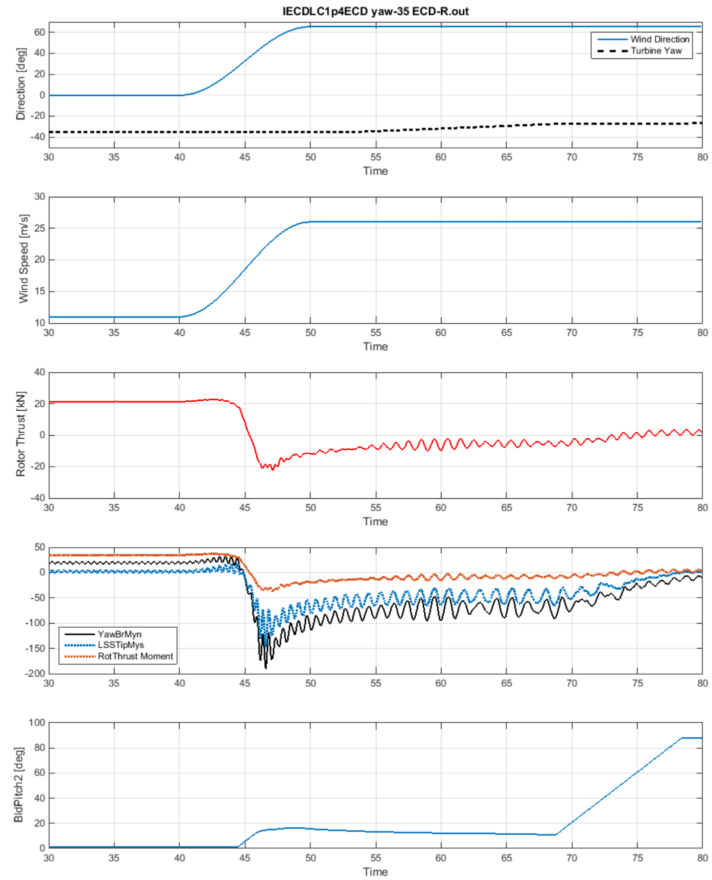
Nacelle Overturning Moment

Test max fast yaw error settings (60 deg setting)

PAUSE alarm; -30 deg yaw



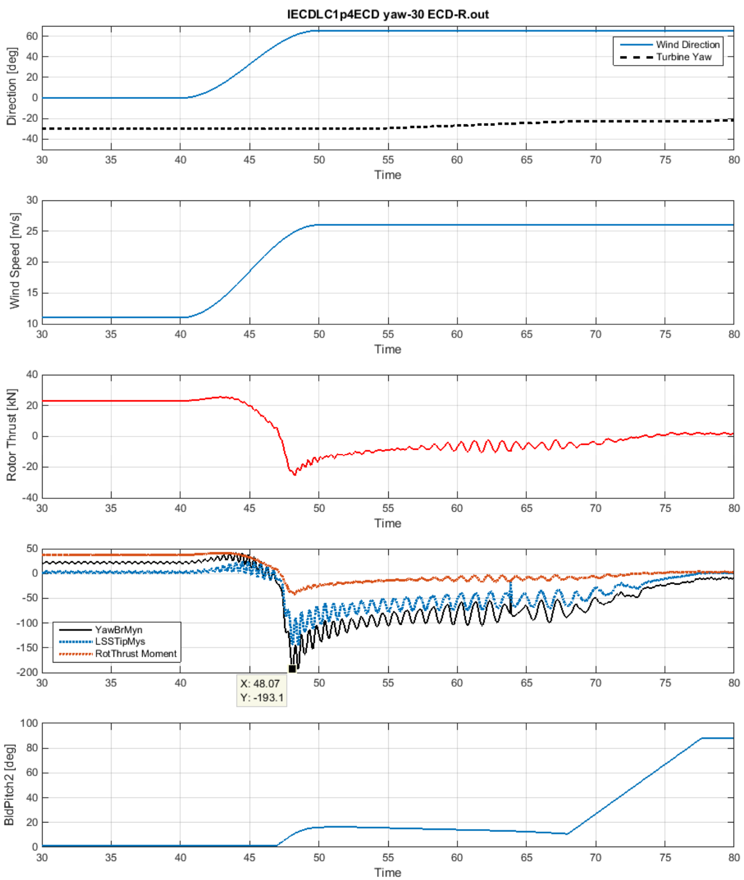
PAUSE alarm; -35 deg yaw



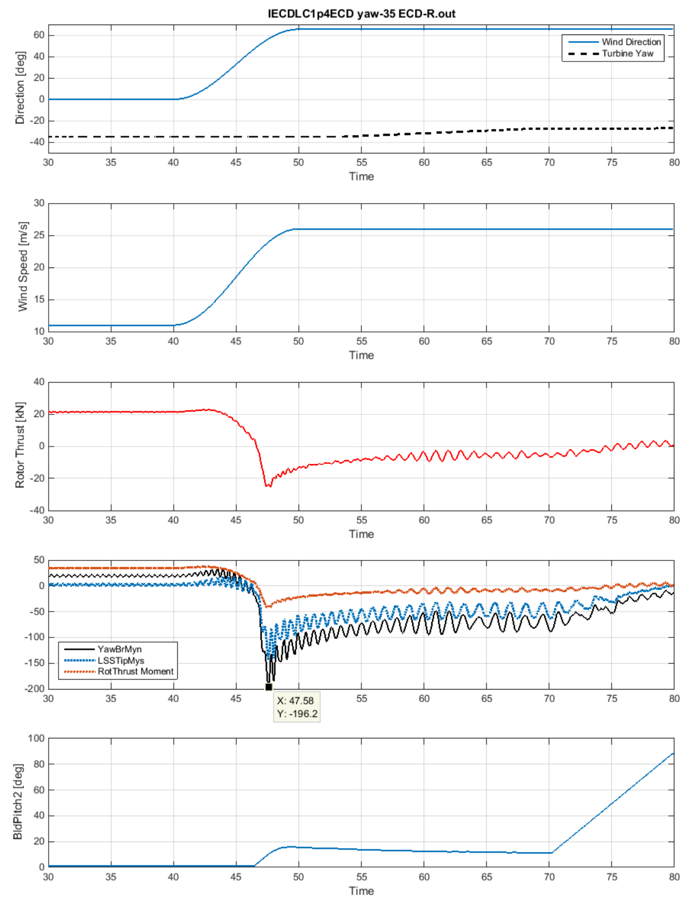
Nacelle Overturning Moment

Test max fast yaw error settings (80 deg setting)

PAUSE alarm; -30 deg yaw



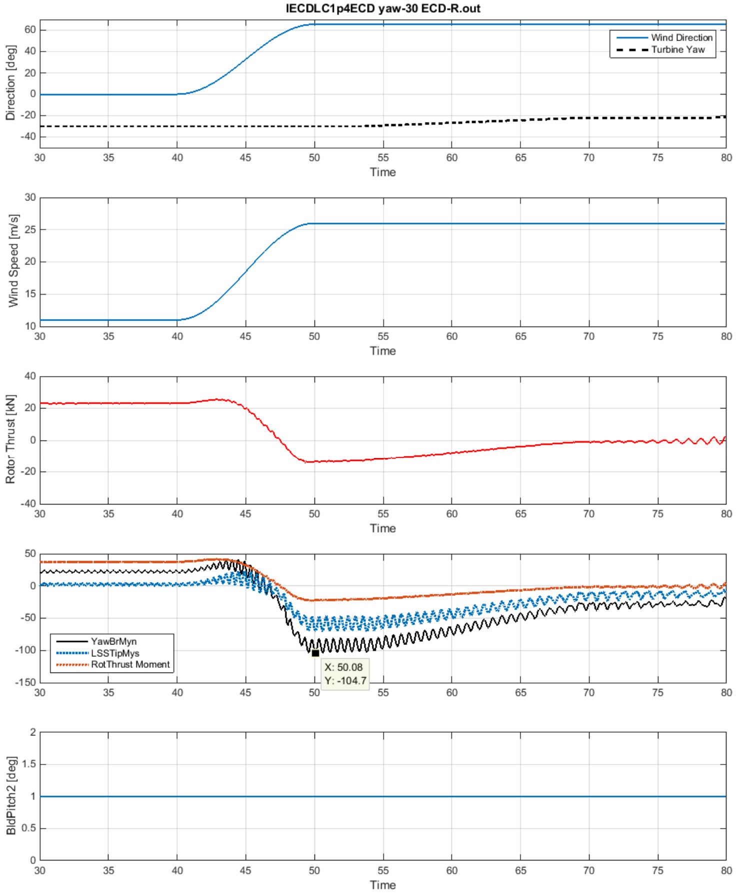
PAUSE alarm; -35 deg yaw



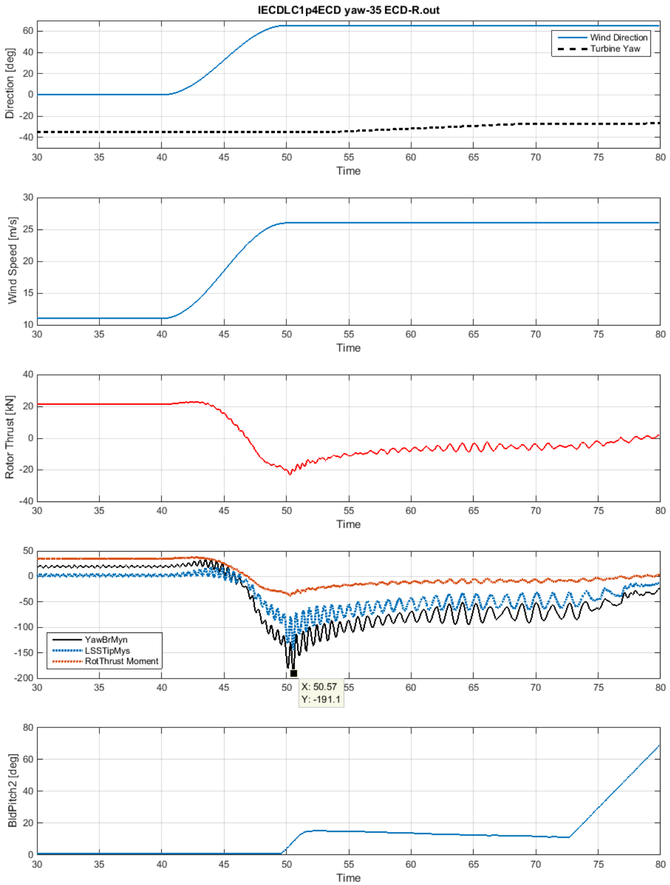
Nacelle Overturning Moment

Test max fast yaw error settings (100 deg setting)

PAUSE alarm; -30 deg yaw



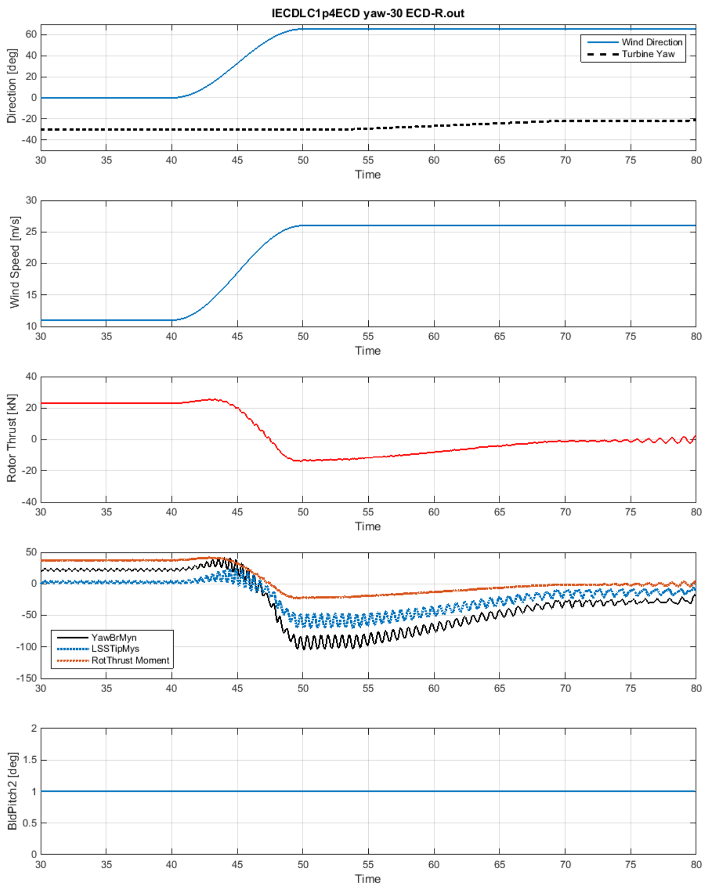
PAUSE alarm; -35 deg yaw



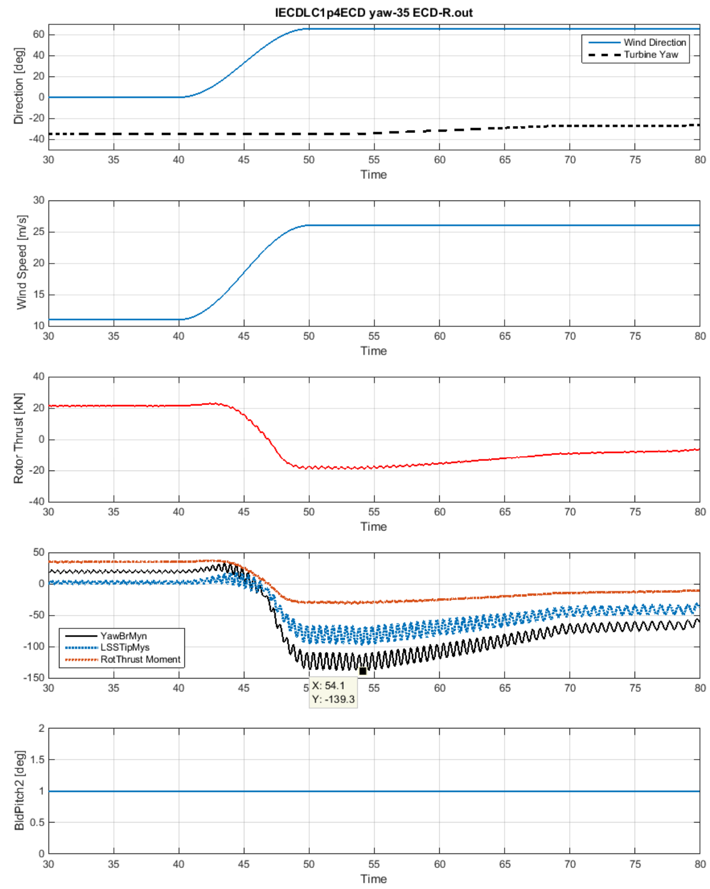
Nacelle Overturning Moment

Test max fast yaw error settings (120 deg setting)

PAUSE alarm; -30 deg yaw



PAUSE alarm; -35 deg yaw

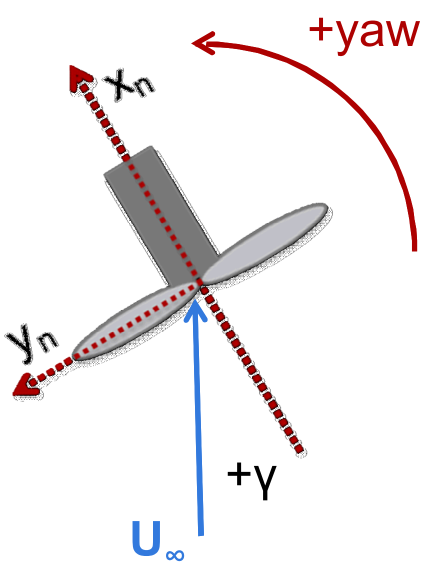


Conclusion:
The FAST and SWiFT convention have the same resulting definition for yaw error, but arrive at that differently where positive yaw is defined opposite.

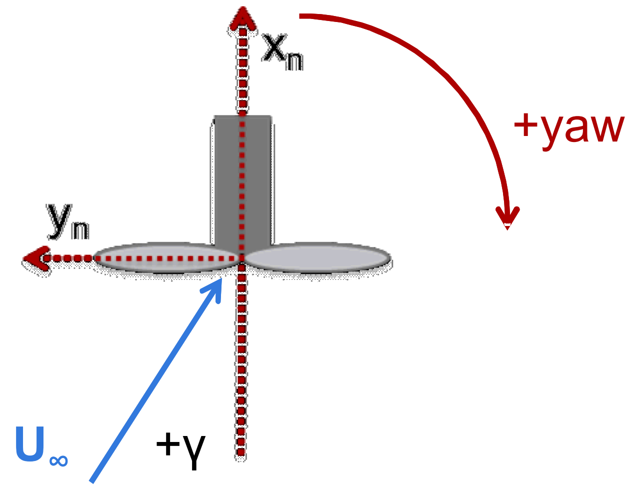
COORDINATE SYSTEM DEFINITION FOR FAST AND SWIFT CONVENTIONS

Coordinate System

FAST



SWiFT



γ_{FAST} = yawHeading - windDirection

γ_{SWiFT} = windDirection – yawHeading

γ_{SWiFT} = nacelleSonicWindDirection